ObservAir

Operating Manual

Distributed Sensing Technologies

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1. Introduction

The ObservAir is an air quality sensing platform that provides accurate pollutant concentration measurements in real time. Key features include:

- **Modular:** The ObservAir is centered around a black carbon (BC) sensor, and can optionally monitor up to two of the following seven gaseous pollutants: CO, NO, NO_2, SO_2, O_3, H_2S, and VOC.

- **Portable:** The lightweight (600g) and compact (120x80x45 mm) ObservAir is easily deployed in both stationary and mobile monitoring applications.

- **Connected:** All ObservAir units support WiFi and USB communication protocols, and include a 16GB removable SD card for onboard data storage. Units may also be supplemented with an LTE communication module and a GPS unit for location logging. An integrated mobile app and optional data backend services enable real-time air quality monitoring, sensor diagnostics, and data collection.

- **Accuracy anywhere:** Using DSTech's proprietary environmental compensation algorithms, each ObservAir is individually 'trained' to maintain measurement accuracy even in harsh operating environments (e.g. outdoors) where existing air quality instruments typically suffer.

- **Network-ready:** With up to 24 hours of battery life, flexible wireless communication options, and environmental compensation, the ObservAir is ready for networked deployments at a moment's notice.

- **Flexible:** Accessories are available to enable a wide range of monitoring applications. Environmentally controlled outdoor enclosures and solar panels are available for extended stationary measurements in harsh conditions. Optional sensors can be outfitted to measure particulate matter pollution, ambient meteorological conditions, and other environmental factors. Custom mounting and packaging solutions for mobile and airborne platforms are also available on request.

The ObservAir is designed to be easily deployed anywhere, and trusted to deliver accurate air quality measurements reliably and conveniently. If you have any questions about integrating the ObservAir into your air quality monitoring efforts, please contact us at info@dstech.io.

1.1. Principle of operation

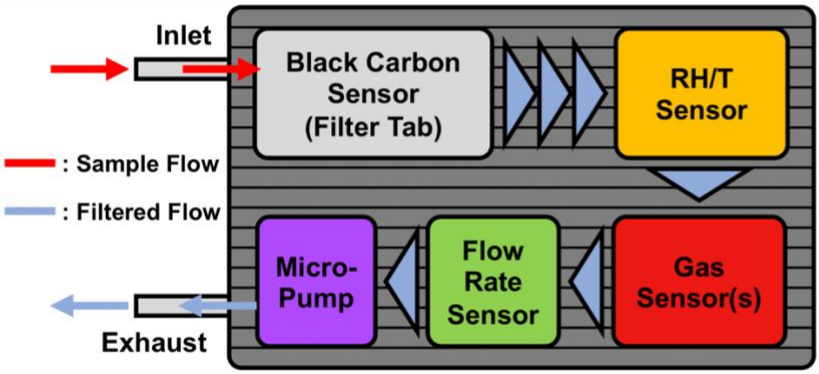


Figure 1. Functional diagram of the ObservAir

The ObservAir is centered around an aerosol absorption photometer configured to measure concentrations of black carbon (BC). BC is a type of particulate matter (PM) pollution generated by the incomplete combustion of fossil fuels or biomass. For most purposes, BC is functionally defined as the light-absorbing component of PM pollution. The ObservAir's micropump first draws air into the inlet and through a fibrous aerosol filter. that is mounted on black supporting material (the disposable filter tab). As light absorbing PM collects on the fibrous filter, BC concentrations are calculated in real time. Downstream of the photometer, a relative humidity and temperature sensor records environmental sampling conditions, and optional electrochemical cells measure up to two gaseous pollutants. Air then passes through the flow rate sensor and is exhausted by the pump.

1.1.1. Aerosol absorption photometer (Black carbon)

A schematic of the ObservAir's aerosol absorption photometer is provided below. Photodiodes continuously monitor the intensity of 880 nm light transmitted from an LED source through two aerosol filters. As polluted air is drawn through the photometer, light absorbing BC accumulates on the first ‘signal’ filter and the transmitted light intensity attenuates predictably over time. The filter collection area is 3 mm in diameter. After the first filter, the air flow passes through a second ‘reference’ filter assembly that is identical to the first. Since the air is filtered (devoid of PM), the intensity of light transmitted through the reference filter is unaffected by BC concentrations. By comparing the reference light intensity to that measured at the signal filter, it is possible to isolate the light attenuation resulting from BC absorption alone, while largely eliminating other factors.

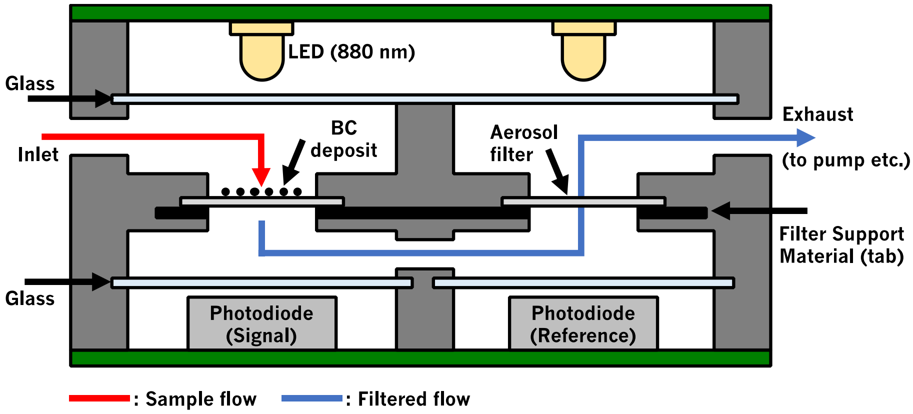


Figure 2. Schematic of the aerosol absorption photometer

Optical attenuation (ATN) is defined in terms of the two light intensity measurements, as shown below. In the ObservAir, both measurements are reported as the bit count from the photodiodes' Analog to Digital Converter (ADC), ranging from 0 to 8388607 (full scale 23-bit output).

$$ATN = 100 \times \ln\left(\frac{I_{ref}}{I_{sig}}\right) \qquad (1)$$

I_{ref} = Light intensity through reference filter (ADC count)
I_{sig} = Light intensity through signal filter (ADC count)

Using the ATN measurements, BC concentrations are calculated using the fundamental equation:

$$BC(t_i) = \frac{A}{MAC \cdot Q(t_i)} \cdot \frac{\Delta ATN}{\Delta t} = \frac{A}{MAC \cdot Q(t)} \cdot \frac{ATN(t_i) - ATN(t_{i-1})}{t_i - t_{i-1}} \qquad (2)$$

BC(t_i) = Black carbon at time t_i (μg/m^3)
A = Filter collection area (D = 3mm) = 7.07x10^{-7} m^2
MAC = Mass absorption coefficient of BC at 880 nm = 7.8x10^{-6} m^2/μg

$Q(t_i)$ = Flow rate at time t_i (m^3/sec)
ΔATN = Difference of two ATN measurements = $ATN(t_i)$- $ATN(t_{i-1})$
Δt = Measurement interval (seconds) = t_i - t_{i-1}

The Mass Absorption Coefficient (MAC) is a calibration factor that relates the time differential of ATN to BC concentrations in the flow. The MAC varies depending on the air pollution source, PM composition and other factors. By default, the ObservAir uses a MAC of 7.8 m^2/g, but this value may be adjusted following cross-calibration with a reference instrument. For the default factors specific to the ObservAir, Equation (2) simplifies to:

$$BC(t_i) = \frac{K}{Q(t_i)} \cdot \frac{\Delta ATN}{\Delta t} \qquad (3)$$

K = ObservAir default constant = 5438461.5 μg · ccm · sec/m^3
$Q(t_i)$ = Flow rate at time t_i (ccm)

Note: Flow rate (Q) is input in units of cubic centimeters per minute (ccm).

1.1.2. Electrochemical cells (Gaseous pollutants)

The ObservAir uses interchangeable electrochemical cells to monitor up to two toxic gases: Carbon monoxide (CO), nitric oxide (NO), nitrogen dioxide (NO_2), ozone (O_3), sulfur dioxide (SO_2), hydrogen sulfide (H_2S), and volatile organic compounds (VOC). O_3 cells must always be paired with NO_2.

Air diffuses through a membrane and comes into a contact with the cells working electrode, as shown in Figure 3. The analyte gas oxidizes or reduces the working electrode, and generates a small electrical current that is proportional to the analyte gas concentration in the air sample. The reference electrode does not contact air and generates a baseline current. By comparing the electrical currents generated by the working and reference electrodes, gas concentrations are logged in real time.

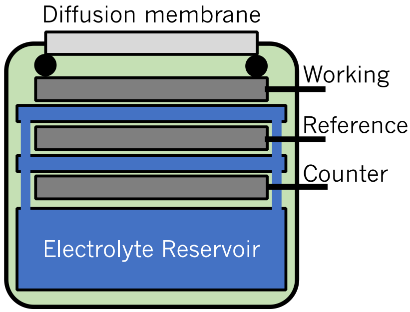


Figure 3. Schematic of electrochemical cell for monitoring gaseous pollutant concentrations

The electrical currents from the working and reference electrodes are amplified and converted to a voltage signal for digital acquisition. Using these two voltage signals, gas concentrations are calculated as follows:

$$C_{gas}(t) = span \cdot \left(\frac{V_{working}(t) - V_{ref}(t)}{Code \cdot Gain \cdot 10^{-9}}\right) + zero \quad (4)$$

$C_{gas}(t)$ = Gas concentration at time ‘t’ (ppm)
$V_{working}(t)$ = Voltage from working electrode at time ‘t’ (V)
$V_{reference}(t)$ = Voltage from reference electrode at time ‘t’ (V)
Code = Calibration code (nA/ppm).
Gain = Voltage gain (V/A)
span = Span calibration factor
zero = Zero calibration factor (ppm)

Code is the factory calibration factor, specific to each individual cell. The code for each cell is logged on the SD card’s Settings file, as outlined in Section 3.6.1. *Gain* is gas specific and constant across cells – it is set in the gas sensing circuitry. *Gain* is $8x10^5$ V/A for all gas species except for NO_2 and O_3, where it is equal to 7.3 $x10^5$ V/A. The span and zero calibration factors (*span* and *zero*, respectively) are determined experimentally for each cell, as outlined in Section 4. By default, the *span* and *zero* are set to 1 and 0, respectively, and are stored to the SD card.

The NO_2 and O_3 gas cells are identical, except that the NO_2 cell is outfitted with a chemical filter to remove O_3 from the sample. The O_3 gas cell has no filter and outputs a signal that is proportional to the concentration of both O_3 AND NO_2 in the sample. As a result, each O_3 cell comes with two factory calibration codes, representing the cell's response to O_3 and NO_2 individually. The O_3 cell must be paired with an NO_2 cell, and concentrations are calculated as follows:

$$C_{O3}(t) = span \cdot \left(\frac{V_{gas}(t) - V_{ref}(t) - C_{NO2}(t) \cdot Code_{NO2} \cdot Gain \cdot 10^{-9}}{Code_{O3} \cdot Gain \cdot 10^{-9}} \right) + zero \quad (5)$$

$C_{O3}(t)$ = Ozone concentration at time 't' (ppm)
$C_{NO2}(t)$ = Nitrogen dioxide concentration at time 't' (ppm) – from other cell
$Code_{O3}$ = Ozone cell's ozone calibration code (nA/ppm)
$Code_{NO2}$ = Ozone cell's nitrogen dioxide calibration code (nA/ppm)
Gain = 7.3 $\times 10^5$ V/A

1.2. Environmental compensation

All air quality instruments are susceptible to environmental fluctuations. For example, the temperature sensitivity of the aerosol absorption photometer's LEDs, photodiodes, and other electronics results in erroneous or inaccurate BC measurements during rapid environmental changes, such as may be expected diurnally when the sensor is deployed outdoors. As a result, traditional instruments must be housed in dedicated stations maintained at stable operating conditions, which is costly and cumbersome. In order to overcome these limitations, the ObservAir incorporates proprietary hardware and software features to minimize the sensor's environmental dependence. **These unique features enable the ObservAir to accurately and reliably monitor air pollution concentrations over extended outdoor deployments, as is needed for practical networked applications.**

Hardware compensation features include the aerosol absorption photometer's active reference filter (see Section 1.1.1). Since clean, particle-free air is drawn through the reference filter, the transmitted light intensity is largely dependent on the flow's temperature and humidity content. By passing the same air through both filters and monitoring each intensity measurement independently, the ObservAir corrects for the photometer's environmental sensitivity and other measurement artifacts (e.g., water absorption in the filter). The sensor is also outfitted with temperature control hardware and other proprietary design elements that preserve measurement accuracy in harsh environments.

Similarly, the gas sensing cells are outfitted with hardware features to reduce environmental sensitivity. Each cell outputs two signals, each generated by a separate electrode. The first 'working' electrode exposed to air, and is sensitive to both the analyte gas and operating conditions. The second 'reference' electrode is not exposed to air, and is therefore only sensitive to the cell's operating conditions. By comparing these two signals, the response from gas analyte concentrations can be isolated.

1.2.1. Black carbon (BC) compensation

While hardware features contribute significantly to correcting the ObservAir's environmental dependence, some BC measurement artifacts remain that must be corrected by software. This software compensation centers on DSTech's proprietary environmental training approach. Prior to delivery, all ObservAir units sample filtered air for at least 24 hours while being subjected to fluctuating environmental conditions. Using the data collected during this training period, the unique environmental dependence of each ObservAir's absorption photometer is modeled mathematically. The models are uploaded to each unit, and used to correct BC concentration measurements in real-time. Each ObservAir is delivered with its own unique zero-calibration sheet, as shown in Figure 4 below. The calibration sheets show the sensor's baseline environmental dependence and black carbon measurement performance both before and after compensation. The sensor also carries out regular calibration and diagnostic checks of the underlying electronics, and includes other software features to maintain and validate photometer performance.

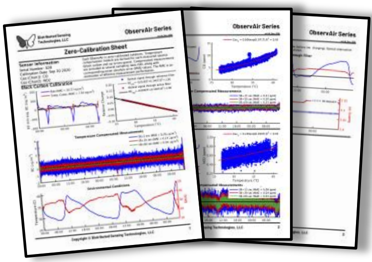


Figure 4. Each ObservAir comes with its own zero-calibration sheet

Details regarding the onboard BC compensation algorithm and it's derivation can found in the publication below. Please note that this publication describes the operation of the Aerosol Black Carbon Detector (ABCD), an academic prototype of the ObservAir. The underlying compensation methods and principles remain the same as that shown in the publication, although experimental procedures and data processing have been significantly improved in the ObservAir.

BC compensation publication: Caubel, J.; Cados, T.; Kirchstetter, T. "A New Black Carbon Sensor for Dense Air Quality Monitoring Networks". Sensors 18.3 (2018): 738-745.

1.2.2. Gas compensation

The electrochemical cells can also be compensated for environmental sensitivity, but this is not done at the DSTech factory (like black carbon). The electrochemical cells' sensitivity varies depending on operating conditions, and so compensation factors derived in the lab tend to drift significantly when the sensor is deployed to the field. As a result, it is best to derive compensation factors by collocating the ObservAir with a reference instrument in the intended deployment location. This calibration should be conducted after the sensors have been allowed to acclimate to operating conditions for at least a few days. Gas concentration data from the ObservAir and reference instrument is sent to DSTech, and compensation factors are derived and uploaded remotely by our staff using the online portal. The environmental sensitivity of each gas cell is compensated using a multivariate linear model, derived with machine learning. Please contact us at info@dstech.io for more information on this procedure.

1.3. Base package contents

Each ObservAir comes with the following base set of accessories and supplies:

- 10 replacement filter tabs
- Micro-SD card with 16 GB capacity
- Charger (US Plug) and 3-foot (1 m) micro-USB cable
- 1-foot length of conductive sample line
- Zero-calibration sheet
- Quick-start guide

2. Technical Specifications

The ObservAir's technical specifications are summarized in the tables below. All electrochemical cells are sourced from Alphasense. Gas measurement performance specifications are adapted from data provided by the manufacturer, and where possible, DSTech validation of the electrochemical cells in the ObservAir platform. All baseline measurement noise specifications are derived from data collected while the ObservAir is sampling clean ('zero') air. More information on the electrochemical cells can be found at www.alphasense.com

All measurement performance specifications are derived from ObservAir data collected at a sample flow rate of 100 ccm near standard atmospheric conditions: Temperature and relative humidity (RH) ranging from 15 to 30°C and 25 to 40%, respectively.

2.1. General specifications

Air pollution measurement species	**Standard:** Black carbon (BC) aerosol				
	Optional: CO, NO, NO_2, SO_2, H_2S, O_3, VOC (up to 2)				
Principle of operation	**Black carbon:** Filter-based light absorption (880 nm)				
	Gases: Electrochemical cells				
Communications	**Standard:** Wi-Fi, Bluetooth, USB				
	Optional: LTE (SIM card can be included)				
Sample air flow rate	15 to 150 ccm				
Sample interval	2 to 60 seconds				
Power consumption	≥ 1.0 W @ 50 ccm, ≥ 1.6 W @ 100 ccm flow rate				
Battery life	≥ 24 hours @ 50 ccm, ≥ 16 hours @ 100 ccm flow rate				
Filter life (BC_{avg} = 1μg/m^3)	**Flow rate (ccm)**	25	50	100	150
	Filter life (days)	20.4	10.2	5.1	3.4
Data storage	Removable SD card (16 Gb card provided)				
Operating conditions	Temperature: 5 to 45 °C; RH: 15 to 90%				
Dimensions/Weight	120 x 80 x 45 mm / 450 grams				
Charging	5V DC at 2.1A max (microUSB charger provided)				

Table 1. ObservAir general specifications

2.2. Measurement performance

	Black Carbon Aerosol	Gases							Environmental		Sample Flow Rate
		CO	NO	NO_2	SO_2	H_2S	O_3	VOC	Relative Humidity	Temp.	
Range*	500 μg/m^3	15 ppm (500 ppm)	2 ppm (20 ppm)	2 ppm (20 ppm)	25 ppm (50 ppm)	10 ppm (50 ppm)	15 ppm (20 ppm)	19 ppm (190 ppm)	0 - 100 %	0 - 50 °C	5 - 200 ccm
Limit of detection	0.05 μg/m^3	20 ppb	80 ppb	15 ppb	15 ppb	5 ppb	15 ppb	20 ppb	N/A	N/A	1 ccm
Resolution	0.001 μg/m^3	1 ppb	1 ppb	1 ppb	1 ppb	1 ppb	1 ppb	1 ppb	0.1 %$_{RH}$	0.1 °C	0.1 ccm
Accuracy	± 5%	± 7%	± 1%	± 2.5%	± 1%	± 1%	± 2.5%	± 15%	± 1.5 %$_{RH}$	± 0.2 °C	± 4.5%
Precision	± 3%	Not Available							0.2 %$_{RH}$	0.15 °C	± 2.5%
90% resp. time (sec)	< 8	< 30	< 25	< 30	< 20	<60	<80	< 30	10	> 2	< 2
Power-on stable (min)	30	60	60	60	60	60	60	60	< 1		

* Gas measurement range is adjustable. Stock and (maximum) values shown. Contact us for details.

Note: Gas, humidity, and temperature specifications adapted from OEM datasheets.

Table 2. Measurement performance specifications

Baseline Noise				
Timebase (TB)	2 sec	15 sec	1 min	1 hr
BC (μg/m^3)	0.3	0.1	0.05	0.01
CO (ppb)	20		< 15	
NO (ppb)	80		< 50	
NO_2 (ppb)	15		< 10	
SO_2 (ppb)	15		< 10	
H_2S (ppb)	5		< 5	
O_3 (ppb)	15		< 10	
Temp. (ºC)	0.05			
RH (%)	0.1			
Flow (ccm)	0.1			

Table 3. Baseline measurement noise at various data logging intervals

2.3. Operational limits and warnings

- **Environmental limits:** Only operate the ObservAir within the conditions listed in Table 1: Temperature and relative humidity must remain between 5 to 40°C and 15 to 80%, respectively. Exceeding these limits may damage the sensor.

- **Moisture/rain:** The ObservAir must not be directly exposed to rain or moisture of any kind without a DSTech enclosure. When fitted with external sampling lines, these must be fitted with rain covers or water catches to ensure that water is not aspirated into the sensor. Exposure or aspiration of moisture may permanently damage the sensor.

- **Direct sunlight:** Do not operate the ObservAir in direct sunlight for extended periods without a DSTech enclosure. Even with a DSTech enclosure, direct sunlight may compromise data integrity. Exposing the bare sensor to direct sunlight may result in the sensor overheating, and/or erroneous data generation.

- **Filter replacement:** Filter tab must be changed regularly for best BC measurement performance. Failure to replace the filter over extended periods may result in damage to the pump if the filter becomes completely saturated.

- **Gas cells:** Electrochemical cells must be calibrated regularly and replaced every 2 to 5 years for best performance. Please contact DSTech for information on our calibration services.

- **Do not pressurize the sensor:** Never connect the ObservAir to a compressed gas cylinder (even when fitted with a regulator), air compressor, or other pressure source without a purge valve that is open to the atmosphere. Positive pressure air in the sensor can damage sensing elements and other hardware.

- **Charger:** Only charge the sensor with the included charger or equivalent 2.1A rated USB charger. The included charger is rated for operation at both 110V/60Hz and 220V/50 Hz – simply adapt to local plug style if needed. Do not use chargers rated above 2.1A or below 2.0 A. The ObservAir can also be charged from computer ports that are rated to at least 500mA.

- **Accessories:** Do not use third party accessories with the ObservAir, such as external battery packs, solar panels, etc. without first consulting DSTech Technical Support.

- **Replacement parts:** Only use replacement parts provided by DSTech or an authorized DSTech distributor.

- **Disassembly:** Never disassemble the unit, this voids the warranty and may result in permanent damage to the unit and/or harm to the user. Please contact DSTech Technical Support at info@dstech.io regarding any problems with your unit that cannot be resolved with the instructions provided in this manual.

2.4. Data processing overview

For black carbon (BC) and gaseous pollutant monitoring, data goes through processing in the order summarized below:

1. **Raw signal acquisition:** Digital voltage readings proportional to light intensity (for BC) or electrical current (for gases). These raw signals are always logged to the SD card and Cloud Dashboard unaltered, such that users can calculate pollutant concentrations from scratch using their own methods.
2. **Environmental compensation:** The voltage signals are compensated for their environmental sensitivity, as outlined in Section 1.2.

Compensation factors are derived and uploaded by DSTech, they cannot be modified by the user.

3. **Digital filtering:** The compensated voltage signals pass through a low-pass filter, outlier filter, and other signal processing procedures. This ensures that the voltage signals are not affected by electromagnetic interference or other measurement noise.
4. **Fundamental equation:** Using the processed voltage signals, pollutant concentrations are calculated using the fundamental equations provided in Section 1.1.
5. **Corrections and calibration:** The pollutant concentration data is corrected for artifacts and calibration factors are applied, as outlined in Section 4. This provides the final concentration values that are logged and displayed.

Data from other sensors, such as that used for particulate matter monitoring, are not processed in any way. Data is simply logged from the third-party hardware, which often incorporates data processing procedures similar to that outlined here.

3. Operating Instructions

3.1. Hardware overview

The ObservAir is shown in Figure 5 below. The sample air inlet and outlet nozzles are located on the front panel, and are denoted by arrows facing towards and away from each nozzle, respectively. The SD card slot and USB port are also located next to one another on the sensor's front panel. In Figure 5, the aerosol filter tab protrudes from its dedicated slot through the front panel, as it does during normal operation. On top of the sensor, there is a thumbscrew for securing the aerosol filter tab, and the interactive LED button for sensor control and feedback.

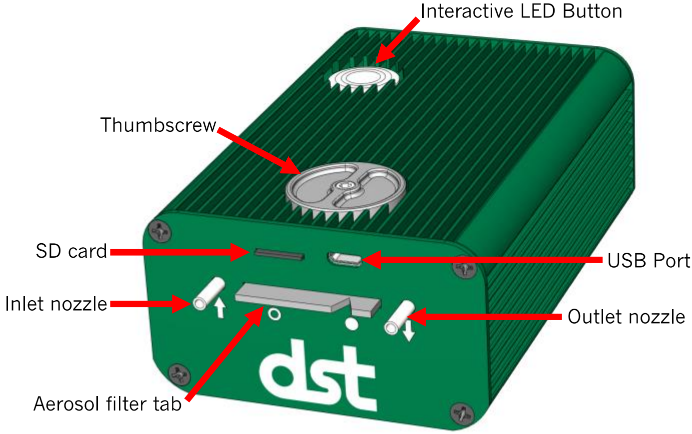


Figure 5. Overview of the ObservAir. Isometric view.

The serial number is displayed on the sensor's bottom surface. Please include this serial number when contacting DSTech technical support.

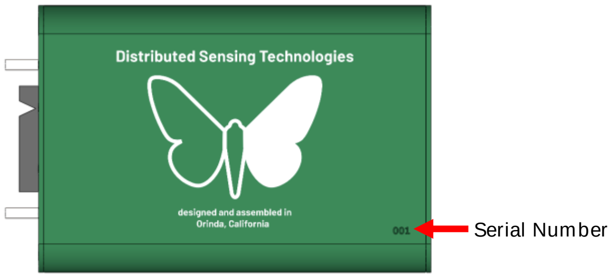


Figure 6. Bottom view of the ObservAir

3.2. Interactive LED button: Sensor display and control

The ObservAir's interactive LED button is used to control basic operational settings and display errors, pollutant concentrations, and other messages.

3.2.1. Sensor startup

To turn on the sensor, press and hold the button for 5 seconds until the LED flashes green, and then release the button. The LED will hold yellow while initializing the bootup sequence then briefly flash red, green, and blue in sequence to indicate that it is starting normal operating mode. If no errors or alarms are detected, the LED will begin to indicate current pollutant concentrations by ‘breathing’ slowly (see Section 3.2.2 below). The sensor should be allowed to warm up for 30 to 60 minutes before monitoring pollutants. For every new start up event, a new data file is created on the SD card (.txt file) and is assigned a filename that contains the sensor’s ID number and the start-up time/date (Section 3.6.1).

3.2.2. Default LED mode: Pollutant concentration display

When the sensor is operating normally (no errors or warnings), the LED slowly glows on and off in a ‘breathing’ pattern. By default, the color of the breathing LED ranges from green to red to indicate the current BC concentration. Green corresponds to a BC concentration of 0 μg/m^3, and red represents concentrations that are higher than or equal to a user defined maximum setting (factory default is 5μg/m^3). LED colors are scaled according to BC concentration between these two limiting values. For example, yellow corresponds to a BC concentration of 2.5 μg/m^3 with the default settings. The LED can also be configured to display gaseous pollutant concentrations. By default, the LED turns off automatically after 20 minutes to conserve battery power, but this delay can be set by the user. The LED can be turned back on by pressing the button briefly, and it will breathe to indicate pollutant concentrations for another 20 minute period. This LED timeout period can also be set by the user. For instructions on configuring the LED display settings, please see Section 3.8.3.

3.2.3. Sensor menu Interface

To interact with the sensor, press and hold the button. The LED will cycle through flashes of different colors and patterns that correspond to the menu items listed in Table 4. When holding the button, the LED cycles through the menu options in the order listed with two seconds in between each option. After reaching the desired menu item, release the button, and the LED will flash the menu item color to confirm the selection. To exit the menu, press and hold the button through the entire menu selection, the LED will start breathing normally, and you can release the button.

LED Flash Pattern		Sensor Function
1x Blue	●	Menu start
1x Red	●	Power off
1x blue	●	Turn Cloud Dashboard on/off
2x Blue	● ●	Provision backend service/WiFi
2x Blue	●	Exit menu – do nothing

Table 4. Index of menu items displayed when holding down the LED button. The LED display will cycle through the options in the order listed until the button is released at the desired selection.

3.2.4. Sensor shutdown (Power off)

To turn off the ObservAir, hold the LED button to cycle through the menu until the first red flash and release. The sensor will flash red two more times and make a chime to confirm that it is shutting down.

3.2.5. Toggle Cloud Dashboard connection

To turn on or off the connection to the Cloud Dashboard, press and hold the LED button to cycle through the menu until the first blue flash and release. An escalating or a descending tune will sound to indicate whether the service has been turned on or off. Note, the instrument must first be provisioned before Cloud Dashboard services can be used (see next Section). Also, note that the instrument must have an accessible internet connection either via WiFi or LTE. Please consult the ObservAir Cloud Dashboard Manual for more information.

3.2.6. Provision Cloud Dashboard service

Before the instrument can access Cloud Dashboard services, it must be provisioned - Network credentials must be provided for the sensor to connect to the cloud, and the sensor must be assigned to your Cloud Dashboard account and configured. To activate provisioning, press and hold the interactive button until the LED flashes blue twice, and release. The instrument will restart into provisioning mode: The LED will slowly breathe blue. Please consult the ObservAir Cloud Dashboard Manual for more information and further instructions.

3.2.7. Sensor alarms and errors

When a sensor error occurs or an alarm is triggered, the LED button flashes red, orange, or yellow. The speed and color of the flashing LED denotes different error codes. If the ObservAir displays an error, refer to Section 6 for troubleshooting instructions to diagnose and resolve the issue.

3.3. Filter tab replacement

To change the filter tab, first release the thumbscrew by turning it counterclockwise for about four full turns (Figure 7). Remove the filter tab by pulling it straight out from the front of the sensor. The filter tab should release from the sensor with little resistance. If there is any resistance, further loosen and/or push down lightly on the thumbscrew to release the filter tab. Second, insert a new filter tab with the notch aligned to the solid white circle on the faceplate, as shown in Figure 8. Third, insert the new filter as far as possible, such that the tip of the notch is flush to the front panel, and hand tighten the thumbscrew firmly.

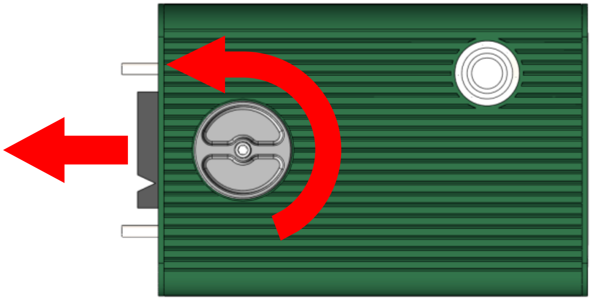


Figure 7. Step 1 of filter tab replacement: Loosen thumbscrew and remove the filter tab

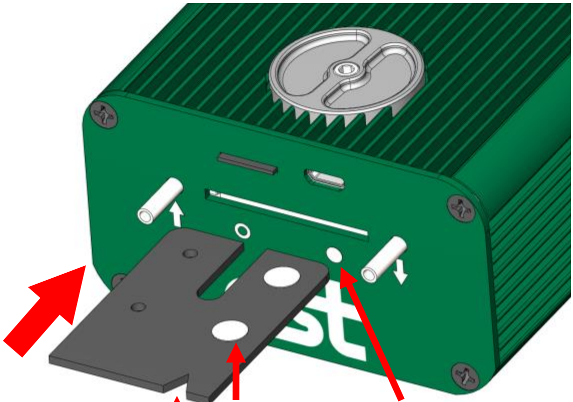
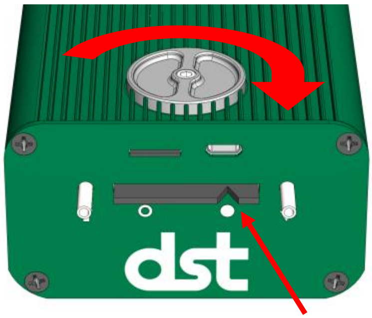


Figure 8. Step 2 of filter tab replacement: Insert a clean filter into the sensor. Align filter notch with the solid white circle on the front panel.



s

Figure 9. Step 3 of filter tab replacement: Push the filter tab into the sensor until it is fully seated (notch should be flush with front panel) and tighten the thumbscrew firmly.

The filter can be changed while the sensor is on or off. If the sensor is on, the LED button will flash purple rapidly while the filter is removed to indicate that the filter is out. When the filter is replaced and tightened, the LED will go back to the normal breathing mode, which indicates current pollutant concentrations. About 30 seconds after filter replacement, the LED will flash green twice to indicate it has automatically reset the attenuation (see next section). If the LED flashes red rapidly after replacement (indicating an error), check that the filter tab has been inserted fully into the sensor and is properly aligned in the slot, as shown in Figure 9). If the filter is changed while the instrument is off, it will take around 1 minute after startup to detect that a filter has been changed, and the ATN will be automatically reset.

3.3.1. Attenuation reset

Optical attenuation (ATN) represents the filter's BC loading. By definition, a clean filter tab (devoid of any BC) has an ATN of exactly 0. However, since the optical depth of each filter intrinsically varies, the light intensity transmitted through the active and reference filters on the tab are not always equal, and the apparent ATN through the clean filter is therefore not equal to zero, as desired.

The ObservAir automatically detects when the filter tab has been changed, measures the apparent ATN, and offsets the ATN data by this value such that ATN = 0 when the filter is clean. If the sensor does not automatically detect the filter change for any reason, the ATN can be manually reset through the backend platform the Cloud Dashboard (both on the app and web browser). The LED will flash green twice to indicate ATN has been reset.

3.4. Battery charging

3.4.1. Charging Outside of Enclosure

The ObservAir's internal battery should be recharged using the included micro-USB cable and 2.1A power adapter. The sensor charges fastest when it is powered off and connected to the 2.1A power supply: a depleted battery will fully charge in about 5 hours in this configuration. When the sensor is off and charging, the LED button shines a solid and turns off when charging is complete. The sensor can also be plugged into the charger while it is powered on and operating. The battery will automatically recharge in this state, but at a lower charging current than when the sensor is powered off. When in normal operation, the LED button will briefly flash yellow once to indicate that a charging cable has been successfully connected. The sensor will also trickle charge while connected to a computer's USB port. A DSTech outdoor enclosure can also charge the ObservAir's internal battery, when the enclosure is connected to a 12V power source.

3.4.2. Charging Inside Enclosure

If the instrument is housed in a DSTech active ventilation enclosure, the instrument will be charged through the enclosure from the DC barrel jack port. Any 12V source capable of 1A output will be sufficient to charge the instrument. The enclosure comes with a power adapter, and optionally, a solar charging kit that plugs directly into the enclosure.

3.5. Active Ventilation Enclosure

The Active Ventilation Enclosure is designed to enhance the deployment capabilities of the instrument, allowing for both indoor and outdoor operation. This versatile enclosure not only improves performance across various settings, but also offers additional features that expand the functionality of the sensor.

By monitoring sensor temperature and regulating temperature changes, the Active Ventilation Enclosure ensures optimal operation. It employs insulation as a barrier against dropping temperatures, while utilizing a fan-driven convection system to cool the sensor when temperatures rise.

The ObservAir sensor is strategically seated within the enclosure at a slanted angle, which facilitates easy access for swapping filters as needed. This design consideration ensures efficient maintenance of the instrument.

Additionally, the enclosure extends the sensor's capabilities by providing ambient measurements of relative humidity and temperature. Optional features include the ability to measure PM1.0, PM2.5, PM4, and PM10 through the integration of a PM sensor. This makes the Active Ventilation Enclosure an essential component for versatile, accurate, and reliable instrument deployment in a variety of environments.

3.5.1. Enclosure Overview

In Figure 10 below, the outdoor enclosure of the ObservAir is depicted, displaying a view from the bottom of the instrument. Key features showcased in this illustration include the 12V barrel jack power input, the inlet and outlet vents, as well as the specific locations of both the particulate matter (PM) sensor and the combined relative humidity/temperature sensor. To maintain optimal instrument temperature, an internal fan draws air into the enclosure through the intake vent and expels it via the exhaust vent.

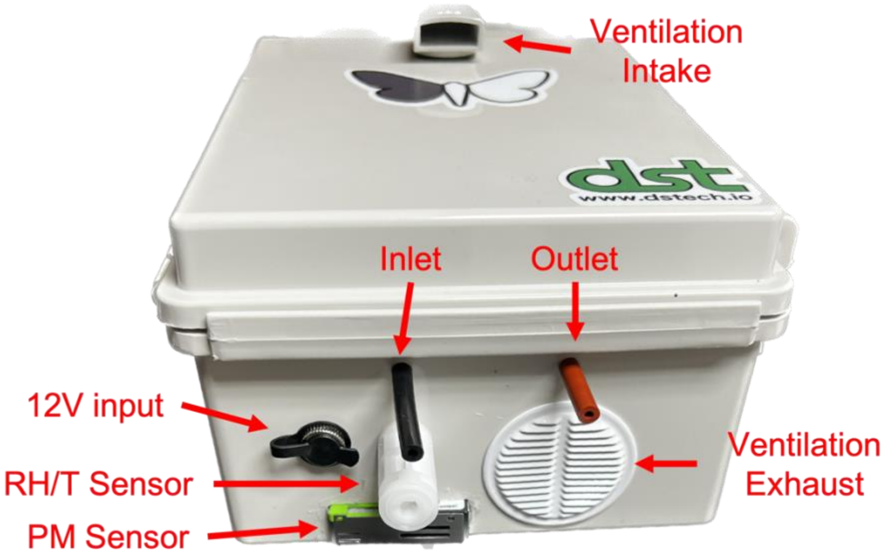


Figure 10. Bottom View of Outdoor Enclosure

3.5.2. Enclosure Mounting

In Figure 11 below, the bottom of the outdoor enclosure is displayed, featuring holes designed for attaching the included mounting hardware. The accompanying image to the right demonstrates the enclosure with the hardware properly secured. The ObservAir's versatile mounting system offers universal fitment, enabling users to fasten the device using screws, zip ties, or any other suitable method based on the deployment location. It is important to note that metal zip ties are the preferred choice; however, if opting for plastic zip ties, black nylon variants are recommended to prevent damage caused by exposure to sunlight.

Figure 11. Enclosure Mounting Points

In Figure 12 below, a deployed ObservAir sensor is illustrated, demonstrating the proper mounting orientation. The bottom side, which houses the PM sensor, RH/T sensor, and inlet/outlet vents, should be positioned facing the ground. This image also includes the optional solar panel attachment.

When mounting the sensor, ensure that all four mounting points are securely fastened to prevent the device from being dislodged by wind or other forces. Additionally, it is crucial to mount the sensor in a manner that minimizes direct exposure to sunlight. If possible, choose a shaded location for deployment, as this is highly preferable for maintaining optimal sensor performance and longevity.

Figure 12. Mounted enclosure showcasing orientation with the inlet/outlet facing the ground.

3.5.3. Solar Power Kit

The optional solar power kit designed to enhance the device's functionality and convenience. The kit includes a versatile mounting bracket capable of supporting one or two solar panels simultaneously. Additionally, a solar charging enclosure is provided, which houses a backup battery to extend the device's operational lifespan, as well as the necessary charging circuitry.

The solar charging enclosure shares the same mounting process as the ObservAir Outdoor Enclosure, with hardware attached to the rear mounting points as detailed in 23

Figure 13 below displays the complete ObservAir system, incorporating the solar charging enclosure, mounting bracket with solar panel, and ObservAir enclosure. This image illustrates the interface between each component and their respective connections.

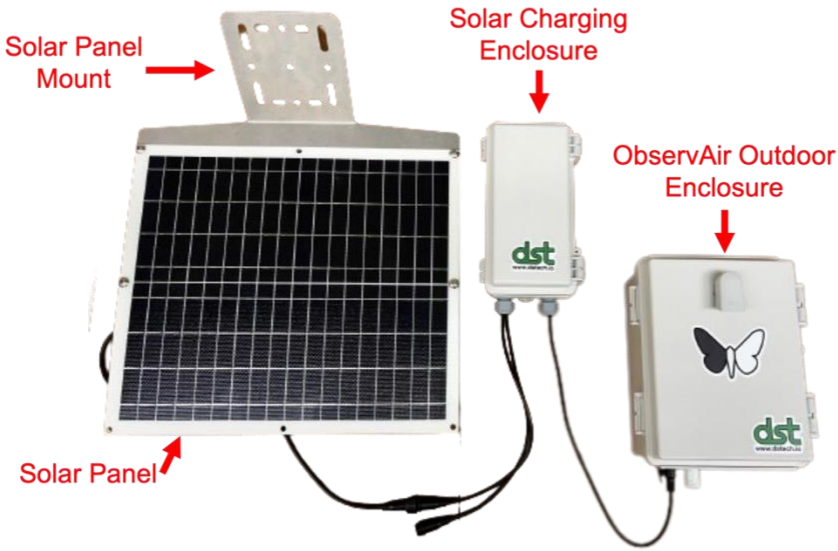


Figure 13. ObservAir System with Solar Kit – This illustration showcases the complete ObservAir system, highlighting the respective connections between the different components. In the image, the second unused connection is designed for use with a dual-panel system.

3.5.4. Mounting Panels to Bracket

The solar panel bracket is a versatile, universal bracket featuring multiple mounting points, allowing for flexible installation using U-bolts, screws, metal zip ties, or other suitable fasteners. This design enables the convenient mounting of the system in various locations, depending on user preference.

The solar panel bracket can accommodate either one or two panels. In a single panel configuration, the solar panel is oriented horizontally and secured with four supplied bolts/nuts. For a dual panel setup, the two solar panels are positioned vertically next to each other, with each panel fastened at three points using three bolts/nuts each.

Figure 14 below illustrates the two different mounting configurations for the solar panel bracket.

Figure 14. Solar Panel Mounting Configurations – The image on the left displays the solar panel bracket with a single panel attached, oriented horizontally. The image on the right demonstrates the dual-panel configuration, with two panels attached vertically side by side.

3.6. Data collection from onboard SD card

While the ObservAir is operating, data is written to the onboard SD card in real time as both a primary means of data collection and a reliable physical backup when wireless data transmission protocols are implemented. By default, the ObservAir creates a new data file every time it starts up. Each file represents a data collection "mission", and is called "XXX_YYMMDD_HHhMMm.txt" where XXX represents the ObservAir unit's ID (or mission name), followed by the date and time of startup. The SD card also contains a file called "Settings_DataXXX.txt" (where again XXX represents the unit's ID or mission name) that contains a running log of the sensor's operational settings. A comprehensive overview of both files' contents is provided below.

3.6.1. Settings file

When a new mission name is entered, a new folder is created with the name of the mission, and a new settings file is be generated within it. A new mission is created either by restarting the instrument, or inputting a mission name. The settings file is composed of four sections:

1. **Header (first line):** The name of the corresponding data file for which the listed sensor settings apply.

2. **Instrument Settings:** This field contains information on the sensor's configuration and operational settings. Fields are defined below and appear in the order listed.
   a. **SN** Serial number.
   b. **user ID:** User assigned sensor ID. Factory default is "DSTech OA" followed by the sensor's serial number.
   c. **Version:** Software version number.
   d. **Hardware:** Hardware version number.
   e. **LEDboard:** Optical board version number
   f. **Firmware:** Firmware version number.
   g. **flowRate:** Sample flow rate setting in units of ccm. Factory default is 100 ccm.
   h. **samplePeriod:** The data collection sample rate in seconds. Factory default setting is 2 seconds.
   i. **envComp:** DSTech's proprietary environmental compensation algorithms are active ('True') or pollution concentration measurements are direct from the sensor(s) and uncompensated ('False'). Default setting is True.
   j. **DLPFilter:** Digital low pass (DLP) filter is active ('True') or turned off ('False'). The DLP filter decreases measurement noise but increases the minimum 90% response time from ~2 to 8 seconds when monitoring BC concentrations. Gas measurement response time is minimally affected. Default setting is True.
   k. **ledDispMode:** Pollution concentration data displayed using the LED button in breathing mode. The LED can also be set to display only sensor alerts, or be turned off completely. Options are 'BC', 'GAS1', 'GAS2', 'ALERT', or 'OFF'. Default setting is 'BC'.
   l. **LEDra:** Running average, in seconds, applied to the pollution concentration data displayed using the LED button. Lower running average values provide higher time resolution but the LED color display may fluctuate due to sensor noise, while higher running average values provide a smoother display with lower time resolution. Default setting is 90 seconds.
   m. **LEDmaxConc:** Maximum concentration setting for the LED display. Default is 5 µg/m^3 of BC (default ledDispMode setting).
   n. **LEDtimeout:** The time duration, in minutes, before which the LED display turns off automatically. Default is 20 minutes.
   o. **maxATN:** Maximum optical attenuation (ATN). When filter loading is above this value, an alarm is triggered. Default is 80.

p. **timeZone:** Time zone in hours relative to GMT. For example, New York is represented by “-4” (GMT- 4:00). Default is 0.
q. **GPS:** Optional GPS unit is logging when ‘True’ and powered off when ‘False’. Default is ‘False’.
r. **GPS_samplePeriod:** Polling time for GPS to acquire coordinates in seconds. Factory default is 10 seconds.

3. **Factors:** This field contains calibration and environmental compensation factors for each pollutant species monitored onboard the ObservAir unit. Most factors in this field are for DSTech’s internal protocols, but those pertinent to the end user are listed below:
   a. **BC_mref, BC_bref, BC_msig, BC_bsig:** Environmental compensation factors for black carbon measurement. Derived and uploaded at factory.
   b. **BC_MAC:** Mass absorption coefficient for BC determination (see Section 1.1.1) in m^2/g. Default is 7.8 m^2/g.
   c. **BC_FLcorrFactor:** Filter loading correction factor being applied.
   d. **FRm:** Slope calibration factor for flow rate sensor in ccm/V. Set at factor.
   e. **FRb:** Intercept calibration factor for flow rate sensor in ccm. Set at factory.
   f. **FRcal:** Flow rate calibration factor. Default value is 1.0.
   g. **Gas1:** Gas species measured by the first optional gas sensor.
   h. **Code1:** Calibration code for the first optional gas sensor. Each gas sensing cell has a unique code from the manufacturer (see Section 1.1.2). Unit = nA/ppm.
   i. **Gas1span**: Span calibration factor for first gas cell. Default value is 1. Must be determined experimentally by user. Unitless.
   j. **Gas1zero**: Zero calibration factor for first gas cell. Default value is 0. Must be determined experimentally by user. Unit = ppm.

   Note 1: If a second gas cell is included in the sensor, a second set of factors *f* through *i* will be written. All factors are the same as the first, except denoted by the number 2.

   Note 2: For an ozone cell, two *Codes* will be given – One for the ozone sensitivity (Code2_O3) and the other for nitrogen dioxide (Code2_NO2). Ozone cells are ALWAYS paired with nitrogen dioxide cells, and mounted in the second slot (Gas1 = NO2, Gas2 = O3).

4. **colNames:** Names of the fields logged in the data file as they appear on each line. For the base unit ObservAir, without gas sensing, the following column names will be listed

a. **TS:** Timestamp in the format: YYYY-MM-DD HH:MM:SS
b. **BC_Iref:** Black carbon (IR) reference intensity from the aerosol absorption photometer. Value is expressed in terms of the ADC's (analog to digital converter) raw count. Full scale value is 8388607.
c. **BC_Isig:** Black carbon (IR) Signal intensity from the aerosol absorption photometer. Value is expressed in terms of the ADC's raw count. Full scale value is 8388607.
d. **BC_ATN:** Black carbon (IR) optical attenuation (unitless)
e. **BC:** Black carbon in $\mu g/m^3$
f. **RH:** Relative humidity in %.
g. **T:** Temperature in ^oC.
h. **FR:** Sample flow rate in ccm.
i. **Vbat:** Battery voltage in volts.

If the unit has gas sensors onboard, the following columns will be appended to those above:
a. **GAS e.g. 'CO':** Gas concentration in ppm
b. **GAS_Vref e.g. 'CO_Vref':** Reference output from electrochemical cell in volts.
c. **GAS_Vsig e.g. 'CO_Vsig:** Signal output from electrochemical cell in volts.

If the unit is equipped with GPS, the following columns will be appended to those above:
a. **Lat:** Latitude coordinate captured by the GPS unit.
b. **Long:** Longitude coordinate captured by the GPS unit.

If the unit is connected to an outdoor enclosure, the following columns will be appended to those above:
a. **T_EXT:** Ambient temperature in ^oC.
b. **RH_EXT:** Ambient relative humidity in %.

If the unit is connected to an outdoor enclosure equipped with PM, the following columns will be appended to those above:

a. **PM1:** PM_1 concentration in $\mu g/m^3$
b. **PM2.5:** $PM_{2.5}$ concentration in $\mu g/m^3$
c. **PM4:** PM_4 concentration in $\mu g/m^3$
d. **PM10:** PM_{10} concentration in $\mu g/m^3$

3.6.2. Data file

The ObservAir data is written in comma separated value (csv) format to a .txt file. Each line in the file represents a datalogging event, and starts with the character "$". Values are listed in the order provided in the colNames field of the corresponding setting entry. Typical data output from a base model ObservAir measuring only black carbon is shown below. If other sensors are fitted to the unit, such as gases or PM, the output data will be appended to each line in the order listed in the colNames field.

```
$2020-09-15 23:21:26, 6889274, 7486915, 0.4477415,-0.5281, 37.70047, 32.93088, 99.6, 7.66
$2020-09-15 23:21:28, 6889416, 7487140, 0.4477730, 0.0924, 37.63485, 32.93088, 100.3, 7.66
$2020-09-15 23:21:30, 6889638, 7487262, 0.4473400, -1.2549, 37.52956, 32.91753, 100.3, 7.66
$2020-09-15 23:21:32, 6889808, 7487379, 0.4477415, 1.1772, 37.58144, 32.91753, 100.3, 7.66
$2020-09-15 23:21:34, 6890005, 7487519, 0.4491062, 4.0048, 37.62112, 32.93088, 100.3, 7.66
$2020-09-15 23:21:36, 6890185, 7487705, 0.4500246, 2.6575, 37.72641, 32.93088, 100.3, 7.66
$2020-09-15 23:21:38, 6890353, 7487792, 0.4502516, 0.6841, 37.72336, 32.91753, 100.3, 7.66
$2020-09-15 23:21:40, 6890537, 7488002, 0.4504004, 0.4360, 37.73556, 32.90417, 100.3, 7.66
$2020-09-15 23:21:42, 6890700, 7488091, 0.4514685, 3.1003, 37.69894, 32.91753, 100.3, 7.66
$2020-09-15 23:21:44, 6890863, 7488192, 0.4526644, 3.5079, 37.72641, 32.93088, 100.3, 7.66
$2020-09-15 23:21:46, 6891009, 7488308, 0.4539852, 3.8455, 37.76455, 32.94423, 100.9, 7.66
$2020-09-15 23:21:48, 6891181, 7488379, 0.4539719, -0.0397, 37.71267, 32.91753, 99.6, 7.66
$2020-09-15 23:21:50, 6891322, 7488435, 0.4555502, 4.6042, 37.64859, 32.93088, 100.3, 7.66
$2020-09-15 23:21:52, 6891469, 7488522, 0.4567795, 3.5648, 37.67300, 32.93088, 100.3, 7.66
$2020-09-15 23:21:54, 6891617, 7488534, 0.4580860, 3.7495, 37.66232, 32.93088, 100.3, 7.66
```

3.7. Cloud Dashboard Interface (WiFi or LTE)

ObservAir Cloud Dashboard is the recommended interface for interacting with the ObservAir. It enables networked interfacing with ObservAir instruments via smartphone app (iOS/Android) and web browsers. The dashboard can be used to remotely monitor and download data, adjust instrument settings, and facilitate easy deployment of sensor networks.

Internet access is required to access the ObservAir Cloud Dashboard. Consult the ObservAir Cloud Dashboard manual for more information.

3.8. Computer (serial USB) connection

The ObservAir can stream data and receive commands via a USB serial connection to a computer. While any serial monitor may be used to communicate with the sensor, we recommend the free and open source Arduino Serial Monitor for the basic operations outlined in this manual. The ObservAir desktop software is also capable of interfacing with the sensor, but a command terminal is not currently available. See the ObservAir Desktop Software manual for more information.

3.8.1. Connecting to Arduino Serial Monitor

Follow the steps outlined below to connect the ObservAir to the serial monitor.

1. The Arduino IDE can be downloaded and installed from https://www.arduino.cc/en/main/software. Download a version prior 2.0
2. With the sensor turned on and operating normally without errors (LED button is breathing slowly), connect the ObservAir to the computer using the micro USB cable.
3. Open the Arduino software and select the ObservAir's serial port from the "Tools" menu. For Mac OSX, the port is called **/dev/cu.usbserial-DN43xxxx**, as shown in Figure 15 below. Windows does not use port naming, and so the port must be found by process of elimination.
4. In Arduino, open the "Serial Monitor" from the "Tools" menu.
5. From the pulldown menus at the bottom of the Serial Monitor, select the "Both NL & CR" and "115200 baud" settings (Figure 16).
6. With the Serial Monitor configured, ObservAir data is displayed in real time at the time interval set by the user. Commands can also be sent to the sensor using the dialog box at the top of the Serial Monitor window.

Figure 15. Step 3: Select the ObservAir communications port in Arduino.

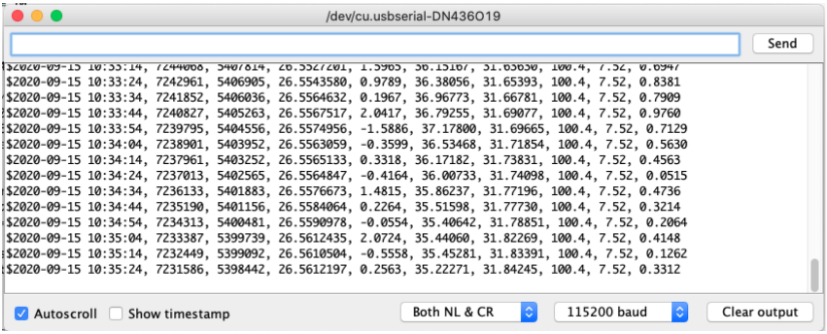


Figure 16. Step 5: Screenshot of the Arduino serial monitor. Select "Both NL & CR" and "115200 baud" from the pull down menus, as shown. The screenshot shows typical live data stream from the ObservAir.

3.8.2. Serial data collection

Serial data is streamed in the same format as it is saved to the SD card (Section 3.6.1). Please note that the Arduino Serial Monitor does not have data logging capability. Any serial logging software can be configured to save ObservAir data using the serial port settings in Table 5.

Port ID	DN43xxxx
Baud rate	115200
Data bits	8
Parity	None
Stop bits	1

Flow control	None

Table 5. Serial port settings

3.8.3. Sensor configuration: Serial commands

Commands can be sent over the Serial Monitor to configure the ObservAir's various operational settings. Most serial commands share the same basic format: **cmdval** where 'cmd' is the name of command, and 'val' is the desired setting value. For example, the command '$setFR$100' sets the sample flowrate to 100ccm. Table 6 documents all available commands. All settings are saved to the SD card for each mission.

Command (cmd)	Value (val)	Function
$setMissonName$val	String	Set mission name (folder name)
$setID$	0 to 1000	Set sensor ID
$setFR$val	30 to 200	Set sample flow rate in ccm
$setSamplePeriod$val	2 to 60	Set measurement period in seconds
$setTimeZone$val	-12 to 12	Set time zone in hours from GMT
$syncTime$	N/A	Sync time with internet server (Time zone must be set, internet must be accessible and credentials provisioned)
$setTime$YYYY,MM, DD,HH,MM,SS	date/time	Manually set clock to specified date/time
$deviceInfo$	N/A	Returns all sensor settings
$setMaxATN$val	10 to 150	Set the maximum attenuation (ATN) value, above which alarm is triggered
$ATNreset$		Reset the attenuation (ATN) to 0
$setLEDdispMode$val	BC, GAS1, GAS2, ALERT, OFF	Set the LED to pollutant concentration display, alerts only, or turn off
$setLEDmaxConc$val	0.2 to 50	Set maximum concentration displayed by LED button (red)
$setLEDra$val	60 to 3600	Set running average size (in seconds) for the LED concentration display
$setLEDtimeout$val	0 to 60	LED display timeout duration in minutes. 0 = LED on indefinitely.
$setDLPF$ val	0 / 1	Toggle the DLP filter applied to the pollutant concentration data

$setEnvComp$val	0 / 1	Toggle DSTech environmental compensation algorithms
$setLTE$val	0/1	Toggle LTE enable
$setGPS$val	0 / 1	Toggle GPS logging
$setGPSsample Period$val	2 to 60	Set the GPS update period in seconds
$setGasSignals$val	0 / 1	Toggle logging of gas sensor(s) signals
$setSaveData$val	0 / 1	Toggle data logging (0 = no data is being saved to SD card)
$setMAC$val	9.0 to 15	Set mass absorption coefficient (MAC)
$setFRcal$val	0.8 to 1.2	Set flow rate calibration coefficient
$setFLcor$val	0-2	Set the filter loading correction coefficient
$setGasZero$chan,val	0/1,-10-10	Set the zero offset of the gas sensor in ppm. Chan is 0 or 1 representing which gas channel to apply the offset to.
$stop$		Pause instrument. Device will stay on, but pump will stop as well as measurements.
$start$		Resume operation after pause state
$restart$		Restart device
$setWIFI$ssid,pw	String,String	Set WiFi credentials of network
$errorInfo$		Returns list of current errors

Table 6. ObservAir serial commands and descriptions

3.9. WiFi connection

WiFi network credentials (name and password) are provided to the sensor during the Cloud Dashboard provisioning process. Provisioning is done on the mobile app (iOS and Android), as outlined in the Cloud Dashboard manual. Once connected, the sensor saves the WiFi credentials to memory. The sensor automatically detects and connects to saved networks. More networks can manually be added to the ObservAir's memory using the ObservAir Desktop application or serial commands.

3.10. Firmware Updates

New versions of the ObservAir firmware are released regularly. Firmware can be updated using a PC, as outlined in the ObservAir Desktop Application Manual. If the instrument firmware version is 1.20.2.r6 or greater (see settings file or online dashboard), firmware can also be updated wirelessly using the over the air (OTA) system. For OTA updates, the instrument must be provisioned with valid WiFi credentials and connected to the ObservAir Cloud Dashboard. Once the sensor is connected, contact DSTech support at info@dstech.io to schedule the OTA firmware transfer.

3.11. External sample lines

The ObservAir can be fitted with external sample lines that extend outside an enclosure and/or pull air directly from a flow conditioning device (e.g. a diluter or dryer). Sample lines should be made of soft rubber tubing with an inner diameter (ID) of 3/32 inch, such that they fit snuggly over the nozzles (1/8-inch outer diameter). Inlet lines must be electrically conductive to prevent particle loss. McMaster-Carr part numbers 1909T3 and 5648K23 may be used for the inlet and exhaust lines, respectively.

4. Data Calibration and Correction Procedures

4.1. Calibration: Black carbon

Each ObservAir comes from the factory with a zero-calibration sheet for the BC sensor, but it is good practice to periodically verify the sensor's baseline performance, especially before and after deployments. To zero-calibrate the BC sensor, an inline HEPA filter (collection efficiency must be >99%) is fitted to the inlet nozzle such that no particulate matter is sampled. DSTech provides HEPA filters for calibration, but inline HEPA filters with barbed fittings are readily available and adapted to the ObservAir's inlet nozzle. Ensure that all connections are well-sealed, and that the ObservAir freely pulls air through the filter (verify that the sensor is pulling the flow rate set by the user).

With filter fitted, operate the sensor for at least 24 hours, preferably at or near the intended deployment site. During zero-calibration, hourly-average BC measurements should not deviate from 0 $\mu g/m^3$ by more than 0.1 $\mu g/m^3$. If this condition is not met, the instrument should be checked for leaks (see Section 5.2). If the problem persists after a successful leak check, contact DSTech for assistance. The ObservAir should provide a robust zero reading during calibration. Zero-calibration is straightforward and can be carried out regularly to verify the sensor's proper operation.

In order to span-calibrate the BC data, the ObservAir must be collocated with a reference instrument. If calibrating relative to another absorption photometer, ensure that the reference instrument is operating at a wavelength of 880 nm, like the ObservAir. Derive a linear regression between the ObservAir and reference BC data, as shown in Equation 6, and note the slope. Generally, this calibration should be done using hourly-average data collected over at least 1 week of collocated sampling.

$$BC_{ref}(t) = m \cdot BC_{OA}(t) + b \quad (6)$$

$BC_{ref}(t)$ = Reference BC measurement at time 't' (μg/m^3)
$BC_{OA}(t)$ = ObservAir BC measurement at time 't' (μg/m^3)
m = Linear regression slope
b = Linear regression intercept (μg/m^3)

Using the slope value, adjust the ObservAir's MAC factor to reconcile the two datasets, as shown in Equation 7. For example, if the ObservAir's BC measurements are consistently 10% lower than the reference (slope of 1.1), the MAC should be *decreased* by 10% to calibrate the ObservAir data relative to the reference.

$$MAC_{cal} = \frac{MAC_{default}}{m} \quad (7)$$

MAC_{cal} = Calibrated MAC (m^2/g)
$MAC_{default}$ = Default MAC (m^2/g) = 7.8 m^2/g from factory

Note: BC measurements are also proportional to flow rate, so it is crucial that the ObservAir's flow rate sensor be calibrated prior to any BC span calibrations (see Section 4.3).

4.2. Calibration: Gaseous pollutants

The most accurate and practical method for gas sensor calibration is collocation with a reference instrument in the intended deployment setting. As discussed in Section 1.2.2, the electrochemical cells' operation varies significantly depending on environmental conditions, so calibration factors derived in the lab will not apply accurately when the sensor is deployed to the field under different conditions.

Calibration can often be done using data from a regulatory monitoring station located near the sensor's deployment site. Using your local environmental protection agency's website (e.g., airnow.gov in the US), locate an air quality monitoring station near you, and deploy your sensors nearby (<1 km in all cases, but < 50 m is best). Depending on the agency, it may be possible to contact your local branch or representative and inquire about collocation opportunities. Whenever possible, calibration should be carried out against Federal Reference Methods (FRM) or Federal Equivalent Methods (FEM) that apply in the deployment jurisdiction. This ensures that the ObservAir's gas data can be meaningfully compared to regulatory data collected elsewhere.

Collocation should be long enough to ensure that a representative sample of gas concentration measurements is collected – typically at least 1 week is required. Compare the data collected by the ObservAir to that collected simultaneously by the reference instrument and derive a linear calibration model, as shown below. Usually, hourly-average concentration data is used to derive the linear regression factors.

$$C_{ref}(t) = m \cdot C_{OA}(t) + b \quad (8)$$

$C_{ref}(t)$ = Reference gas concentration measurement at time 't' (ppm)
$C_{OA}(t)$ = ObservAir gas concentration measurement at time 't' (ppm)
m = Linear regression slope
b = Linear regression intercept (ppm)

Using these factors, the ObservAir data can then be corrected using the equation below. Span and zero factors are uploaded to the instrument over the Cloud Dashboard or serial connection.

$$C_{cal}(t) = span \cdot C_{raw}(t) + zero \quad (10)$$

$C_{cal}(t)$ = Calibrated gas concentration measurement at time 't' (ppm)
$C_{raw}(t)$ = Raw gas concentration measurement at time 't' (ppm)
$span = m$ = Derived linear slope
$zero = b$ = Derived linear intercept (ppm)

Note: The same collocated data collected for gas calibration can be used for environmental compensation. If the sensors are connected to the Cloud Dashboard, simply send the reference data to DSTech – our staff will derive compensation factors for each sensor (using machine learning) and upload them remotely. If the sensors are not connected to the Cloud

Dashboard please contact DSTech for further instructions – both the reference and ObservAir data must be sent manually, and the derived compensation factors must be uploaded to each sensor over serial connection.

4.3. Flow rate calibration

The flow rate sensor is calibrated at DSTech prior to shipment, but sensor output may drift over long periods (weeks or months of operation) and should be re-calibrated periodically using the instructions below:

1. Turn on the ObservAir and allow it to warm-up for at least 15 minutes.
2. Connect ObservAir to a serial monitor (Section 3.8).
3. Set the ObservAir to the desired flow rate setting using the appropriate serial command.
4. Connect a primary flow calibrator, such as a Gilian Gilibrator, to the ObservAir's inlet such that the sensor's intake flow is measured.
5. Collect at least 5 flow rate measurements using the calibrator. The flow rate measurements should not vary by more than ±1 ccm. Take the average of all calibrator measurements: this is the reference value (FR_{ref}).
6. From the serial output or Cloud Dashboard, collect at least 5 flow rate measurements from the ObservAir and take the average: this is the measured value (FR_m).
7. Calculate the calibration factor: $FRcal = FR_{ref}/FR_m$
8. Update the sensor's FRcal factor using the serial command or Cloud Dashboard.
9. Repeat Steps 5 and 6 until the reference and measured values agree within 2 ccm.

Note: If a primary flow calibrator is not available, another flow rate sensor may be used, but clearly the calibration is only as good as the reference measurements collected.

4.4. Black carbon correction: Filter loading

As particulate matter deposits on the filter, the ObservAir uses a simple mathematical relationship to calculate BC concentrations in the sample flow as a function of the light attenuation rate through the filter (Section 1.1.1). As the aerosol filter becomes overly saturated with BC deposits, however, this mathematical relationship degrades and the ObservAir's BC concentration measurements are underreported (lower than the true value). This measurement degradation is known as the 'filter loading artifact'. In the ObservAir it is corrected using the equation below, developed by Novakov and Kirchstetter (See References 1 and 2 at the end of this section).

$$BC_{corr} = \frac{BC_{raw}}{k \cdot \exp\left(-\frac{ATN}{100}\right) + 1 - k} \quad (10)$$

$BC_{corr}(t)$ = Filter loading corrected BC at time 't' (µg/m^3)
$BC_{raw}(t)$ = Raw, uncorrected BC at time 't' (µg/m^3)
$ATN(t)$ = Optical attenuation at time 't'
k = Filter loading correction factor

The filter loading artifact is not static – it depends on the emissions source (e.g. biomass vs. diesel), atmospheric conditions, seasonality, and other factors. Therefore, the filter loading correction factor should be periodically derived at the deployment site. This is done by collocating two ObservAir units, each operating at a different flow rate. Typically, one unit is operated at 50 ccm, while the other is operated at 100 or 125 ccm. As the two filters load unevenly, the two sensors' BC data will diverge: BC measurements from the high flow unit will be lower than the BC measurements from the low flow unit. Using this collocated data, a filter loading correction factor can be iteratively derived that best reconciles the two sensors' BC measurements. Methods for field derivation of the filter loading correction factor are currently being published. Please contact DSTech for more details.

By default, the filter loading correction factor is 0.66 – this factor was derived for urban sampling conditions in California, and has been found to be applicable in similar sampling environments.

The filter loading artifact can be largely eliminated by operating the sensor at low optical attenuation levels (ATN < ~40). However, this requires frequent replacement of the filter which may not always be practical and convenient, and some BC measurement error necessarily remains. Therefore, filter loading correction algorithms should be calibrated and validated for each particular application of the ObservAir, and periodically updated over long-term deployments.

The filter loading artifact is a well-known issue with absorption photometers, and many algorithms have developed and evaluated. Some useful resources have been provided below, and there are many more in the literature.

Filter loading correction references:

1. Kirchstetter, T. W.; Novakov, T. Controlled generation of black carbon particles from a diffusion flame and applications in evaluating black carbon measurement methods. Atmospheric Environment 2007, 41, 1874–1888. https://doi.org/10.1016/j.atmosenv.2006.10.067
2. Jimenez, J.; Claiborn, C.; Larson, T.; Gould, T.; Kirchstetter, T. W.; Gundel, L. Loading effect correction for real-time aethalometer measurements of fresh diesel soot. J. Air Waste Manag. Assoc. 2007, 57 (7), 868–873. https://doi.org/10.3155/1047-3289.57.7.868.
3. Good, N.; Mölter, A.; Peel, J. L.; Volckens, J. An accurate filter loading correction is essential for assessing personal exposure to black carbon using an aethalometer. J. Expo. Sci. Environ. Epidemiol. 2017, 27 (4), 409–416. https://doi.org/10.1038/jes.2016.71.
4. Virkkula, A.; Mäkelä, T.; Hillamo, R.; Yli-Tuomi, T.; Hirsikko, A.; Hämeri, K.; Koponen, I. K. A simple procedure for correcting loading effects of aethalometer data. J. Air Waste Manag. Assoc. 2007, 57 (10), 1214–1222. https://doi.org/10.3155/1047-3289.57.10.1214.

5. Best Practices

5.1. Filter replacement

The filter should be changed when the optical attenuation (ATN) exceeds 80: a commonly accepted ATN threshold for aerosol photometry at 880 nm. Given this optical attenuation limit, the filter's operational life before requiring replacement depends only on the average BC concentration and flow rate of air sampled through the sensor. For an average BC concentration of 1 μg/m^3, Table 1 shows that the effective filter life ranges from 20.4 to 3.4 days as the sample flow rate settings increases from 25 to 150 ccm. Filter life is inversely proportional to both average BC and flow rate, and may be calculated using the equation below. The equation approximates the total sampling time required for the aerosol filter to reach an ATN of 80 for the given input conditions.

$$FL = \frac{510}{BC_{avg} \cdot FR} \qquad (11)$$

FL = Filter life (days)
BC_{avg} = Average BC concentration (μg/m^3)
FR = Flow rate (ccm)

5.2. Leak check

It is best practice to periodically check the integrity of the closed flow path using the instructions below. If the instrument leaks, BC measurements will be compromised, but gas sensor data should remain largely unaffected.

1. Replace the filter while the ObservAir is operating.
2. Plug the ObservAir's inlet port. A simple plug may be fashioned by tying a knot in a length of sample line (soft rubber tubing).
3. Monitor the flow rate measurement using the Cloud Dashboard or serial monitor.
4. After ~1 minute, the reported flow rate should be **less than 3 ccm**. This indicates that the closed flow path is well sealed, as no air can be sampled. If the sensor meets this criterium, it has passed the leak check and can be deployed.
5. If the sensor fails the leak check, first tighten the thumbscrew by 1 full turn and repeat steps 3 and 4.
6. If the sensor still fails, replace the filter and repeat steps 5 to 7.
7. If the sensor fails after these attempts, contact DSTech Technical support at info@dstech.io.

5.3. Flow rate setting: Filter life vs. BC resolution

The filter's operational life decreases at higher flow rates, so it may be tempting to set flow rate at the lowest possible option (25 ccm) and minimize sensor maintenance. However, effective BC measurement resolution also depends on flow rate: Since the filter loads up with BC more rapidly at higher flows, the time rate of light attenuation is more readily detectable, and BC baseline noise decreases. BC baseline noise represents the sensor's effective measurement resolution and is shown for various sampling intervals in Table 3 for a flow rate of 100 ccm.

BC baseline noise is inversely proportional to the sample flow rate. For example, 1-minute BC noise is around 0.025 μg/m^3 at 200 ccm (half that shown in Table 3 for 100 ccm). In this way, higher flow rates provide measurements with higher temporal resolution, but at the expense of filter life. The optimum flow rate setting maintains adequate BC measurement resolution for the monitoring application while maximizing filter life such that sensor maintenance remains convenient and practical. The procedure below outlines the calculation and selection of an appropriate ObservAir flow rate setting.

1. **Determine BC_{avg} and logging interval**: Both of these parameters depend on the sensor application and must be determined by the user. The average BC concentration (BC_{avg}) during the campaign can be estimated by (1) searching the literature or regulatory databases for

representative BC concentration data, or (2) conducting preliminary testing with the ObservAir at a flow rate setting of 100 ccm. The logging interval is dictated by the application context and goals. For example, long-term ambient monitoring may only require hourly measurements, while mobile platforms require rapid data logging every 10 seconds or less. In both cases, these parameters may simply be estimated to set the sensor flow rate initially, and adjusted thereafter depending on the results. As an example, we will choose values of 0.4 ug/m^3 and 1 hour to illustrate each step in this procedure.

2. **Calculate requisite BC measurement resolution:** As a rule of thumb, the baseline noise at the desired logging interval should be < 10% of the expected BC concentration. So for our example, baseline noise should be < 0.1*0.4 = 0.04 μg/m^3 on an hourly basis.
3. **Calculate the minimum allowable flow rate:** From Table 3, find the BC baseline noise at the requisite timebase (2 sec, 15 sec, 1 min, or 1 hour). Since this noise specification is for a flow rate setting of 100 ccm, the minimum required flow rate can be estimated using the equation below. For our example, Table 3 shows that the baseline BC noise at 1 hour is 0.01 μg/m^3, so the minimum flow rate is (0.01/0.04)*100 = 25 ccm. Note that the results of this calculation are bounded by the ObservAir's minimum and maximum flow rate settings: 25 and 150 ccm, respectively.

$$FR_{min} = \frac{Noise_{spec}}{Noise_{req}} \times 100\text{ccm} \qquad (12)$$

FR_{min} = Minimum allowable flow rate (ccm)
$Noise_{spec}$ = Baseline specification from Table 2 (μg/m^3)
$Noise_{req}$ = Maximum BC noise calculated in Step 2 (μg/m^3)

4. **Calculate the maximum filter life:** Using the average BC concentration from Step 1 and minimum flow rate setting from Step 3, calculate the filter life according to the equation provided in Section 5.1. In our example, the maximum filter life is 510/(25*0.4) = ~51 days.
5. **Optimize the flow rate to meet your needs:** Given these limiting values, the flow rate setting can be optimized to meet your needs. For example, if greater BC measurement resolution is desired at the expense of filter life, the flow rate can be increased past the minimum value. Conversely, flow rate may be reduced to achieve the opposite result.

For reference, Table 7 shows the ObservAir's minimum flow rate setting and maximum filter life as a function of average BC concentration and data logging period. The values in the table are calculated according the procedure presented above. Two illustrative scenarios are also provided.

		Data logging period			
		2 sec	15 sec	1 min	1 hour
Avg. BC	0.5 μg/m³	N/A	200/3.1	100/6.3	25/25.0
	1 μg/m³	200*/1.6[a]	100/3.1	50/6.3	25/12.5
	5 μg/m³	60/1.0	25/2.5	25/2.5	25/2.5
	10 μg/m³	30/1.0	25/1.3	25/1.3	25/1.3

Minimum Flow Rate (ccm)*/ Maximum filter life (days)[a]

Table 7. ObservAir's minimum flow rate setting and maximum filter life as a function of average BC concentration and data logging period. The ObservAir cannot provide BC concentration data with a baseline noise < 0.05 μg/m³ on 2-second basis, so the top left cell is empty.

- **Scenario 1:** BC_{avg} = 7 ug/m³, Logging interval = 2 seconds

For this scenario, the BC baseline noise should be ≤ 0.7 μg/m³ at 2-second logging. Using the calculation procedure above, the minimum flow rate setting is (0.3/0.7)*100 = 43 ccm. For these settings, the maximum filter life is ~1.7 days. Alternatively, refer to Table 7 and see that for 2-second measurements of 5 μg/m³ average concentrations, the flow rate setting is 60 ccm. By interpolation, the flow rate can be set to 60*7/5 = 43 ccm.

- **Scenario 2:** BC_{avg} = 0.35 ug/m³, Logging interval = 1 minute

The BC baseline noise should be from ≤ 0.035 μg/m³ at 1-minute logging. From Table 1, the noise is 0.05 ug/m³ at 1-minute and 100 ccm, so the minimum flow rate is (0.035/0.05)*100 = 70 ccm. In Table 7, a flow rate of 100 ccm is recommended for 1-minute measurements at 5 μg/m³. By interpolation, the flow rate can be set to 100*0.35/0.5 = 70 ccm. The filter life can be calculated as 510/(0.35*70) = 20.8 days.

IMPORTANT NOTE: The above considerations do NOT apply to gas sensing. The gas sensors' measurement performance remains largely constant with varying flow rate.

5.4. Operational settings for common applications

Table 8 provides typical BC concentrations and operational settings for some common sampling scenarios. Note that the guidance provided is approximate and intended to serve as an illustrative guide: Some applications may not be well described/served by the parameters listed.

	Average BC (μg/m^3)	Flow rate (ccm)	Time Resolution	Filter life
Ambient: Background/rural	**Low** (0 to 1)	**High** (100 to 200)	**Low** (1 hour)	**High** (Weeks/Days)
Ambient: Typical	**Medium** (0.3 to 5)	**Medium** (50 to 100)	**Low** (1 hour)	**High** (Weeks/Days)
Ambient: Dense Urban	**High** (5 to 50)	**Low** (25 to 50)	**Low** (1 hour)	**Medium** (Days)
Emissions capture (direct source)	**Extreme** (> 100)	**Medium** (50 to 100)	**Medium** (10 to 60 sec)	**Very low** (Hours)
Mobile/Personal	**Medium/High** (0.3 to 50)	**High** (100 to 200)	**High** (2 to 10 sec)	**Low** (1 day)

Table 8. General settings for several monitoring applications

Ambient monitoring: When deploying the ObservAir as a static network node over long periods (weeks or months), the flow rate should be set as low as possible to maximize filter life and reduce the maintenance effort, especially when network sites are remote or numerous. Ambient monitoring applications typically require data with low temporal resolution – hourly measurements are often sufficient – and this helps reduce the flow rate requirements. Referring to Table 7, it can be seen that the minimum flow rate setting of 25 ccm provides suitable hourly measurements for nearly all BC concentrations. However, it should be noted that this achieves a nominal BC measurement resolution that is ~10% of the average concentration, which may not be sufficient for all applications (e.g., regulatory monitoring). If greater resolution is desired, flow rate should be increased to the values listed in Table 8. Similarly, special consideration should be given when conducting long-term monitoring in rural or remote areas with BC concentrations < 0.5 μg/m^3. In these scenarios when filter loading is low, it is generally advisable to operate the sensor at a high flow rate setting (100 to 200 ccm) to maintain BC measurement integrity.

Emissions source characterization: The ObservAir can be configured to characterize emissions from stationary exhaust stacks, vehicle tailpipes and other pollution sources. When sampling emissions directly, do not exceed the ObservAir's maximum temperature, relative humidity range, and pollution concentration ratings (Table 2). As with other instruments, the ObservAir may require that emissions from the source be diluted, cooled, and/or dried. For transient monitoring applications, such as engine testing, measurements are typically required every 2 to 10 seconds, and therefore the ObservAir's sample flow rate must usually be set >100 ccm to maintain adequate measurement resolution. When sampling over long periods (stack monitoring over hours or days), the sample flow rate may be lowered to 25 or 50 ccm to maximize filter life, especially when concentrations are highly elevated. Sampled concentrations depend on the source and flow conditioning system implemented (e.g. diluter), but it is not unusual for BC concentrations to exceed 100 $\mu g/m^3$ when capturing emissions directly.

Mobile monitoring: When sampling from a mobile platform, measurements must be logged as fast as possible to maintain adequate spatial resolution required for the air pollution maps that are ultimately generated. Therefore, the ObservAir should be configured to log concentration data every 2 to 10 seconds at the maximum flow rate setting of 200 ccm to maximize the temporal resolution of both BC and gas concentration measurements. Always operate the ObservAir inside the mobile platform (e.g. car or van) with an electrically conductive sample line running outdoors. Do not mount sensors on the exterior of mobile platforms without the dedicated DSTech mount and enclosure. When mounting the ObservAir inside the mobile monitoring platform, take care to minimize exposure to mechanical vibrations, excessive heat and/or direct sunlight over extended periods.

Personal monitoring: Personal monitoring guidelines largely mirror those provided for the mobile platform: Operate the sensor at a high sample flow rate (100 to 200 ccm) to maximize the quality of BC measurements collected every 2 to 10 seconds. Depending on the application and concentrations sampled, some consideration may be given optimizing the flow rate for filter life (e.g., each filter lasts a full 8-hour workday). The sensor may be mounted inside a bag or from a strap (such as those provided by DSTech), but take care to clip an electrically conductive sample line to the subject's lapel or other appropriate location.

5.5. Indoor/Outdoor monitoring guidelines

The ObservAir can be operated in nearly any indoor environment without modification: The sensor is plugged into a power source and set to run for as long as needed. Exposure to direct sunlight should be avoided over extended periods, as this may cause overheating of the internal components.

For long-term outdoor deployments, the ObservAir should be housed in the DSTech active ventilation enclosure. It is best to orient the sensor with the nozzles facing downwards to prevent the aspiration of rain or moisture.

5.6. Accurate sample flow rate measurements are critical

BC concentrations are inversely proportional to the flow rate of air drawn through the aerosol filter (see Section 1.1.1), so any flow measurement errors translate directly to the reported BC. For example, if the ObservAir's flow rate measurements are 10% lower than the actual value, BC concentrations will be overreported by 10%. Given this proportional relationship, flow rate measurement drift can be post-corrected. In the example above, all collected BC concentration measurements can simply be scaled up by 10% to compensate for the flow rate drift.

When BC measurements are consistently offset from those collected by another ObservAir or reference instrument, miscalibration of the flow rate sensor is almost always responsible. If BC measurements are proportionally lower than the reference value, then it is also possible (but less likely) that the ObservAir is leaking. Given these potential error modes, it is important to validate/calibrate the flow rate sensor output and perform leak checks regularly (see Section 4 for instructions). Since it is not typical for the ObservAir to leak or for the flow rate sensor's output to drift significantly, these routine maintenance tasks are often neglected, and are nearly always the source of BC measurement errors when they do occur. When properly calibrated, the ObservAir's flow rate measurements should be within ±2 ccm of those collected with a primary flow calibrator.

6. Troubleshooting

6.1. LED error codes

The ObservAir constantly runs diagnostic checks to detect and flag measurement errors and warnings. When an error is detected, the LED button flashes rapidly until the error is resolved. The color and speed of the flashing LED indicates the error type, as shown in Table 9 below. Brief instructions on how to resolve each error type are also provided. The exact error can be found in the cloud dashboard, or through the serial command line as described in section 3.7.3 using command “$errorInfo$”.

LED Flash Pattern	Error	Solution
Slow Orange	RH or T out of bounds	Change environment (remove from direct sun, place in cooler location), pause unit until conditions have changed.
Slow Yellow	High attenuation or Low battery	Replace filter. Check that instrument is charging
Fast Yellow	SD card error	Check that SD card is properly inserted. Take SD card out fully and re-insert into the slot.
Very Fast Yellow	Clock error	Reset time according to the instructions in Section 3.8.3.
Slow Red	LED error	Check that filter is properly seated. Replace with new filter.
Fast Red	Flow rate error	Check that nozzles and sample lines are unobstructed.
Very Fast Red	Critical error	Contact DSTech Technical Support.

Table 9. LED error code lookup table.

6.2. Unresponsive sensor

If the ObservAir becomes unresponsive, the software may have crashed and a hard reset is required. A hard reset can be triggered by swiping a magnetic over the top of the sensor in line with the interactive LED button (Figure 17). A magnetic detector is located inside the sensor just below the interactive LED button, and will trigger a hard reset when exposed to the magnetic field. When a hard reset is triggered, the LED will flash green and the sensor will restart into the normal operating mode. If the sensor becomes unresponsive often or on a regular basis, please contact DSTech Technical Support.

Figure 17. Hard reset using a magnet