

CSAT3BH

Three-Dimensional Heated Sonic Anemometer

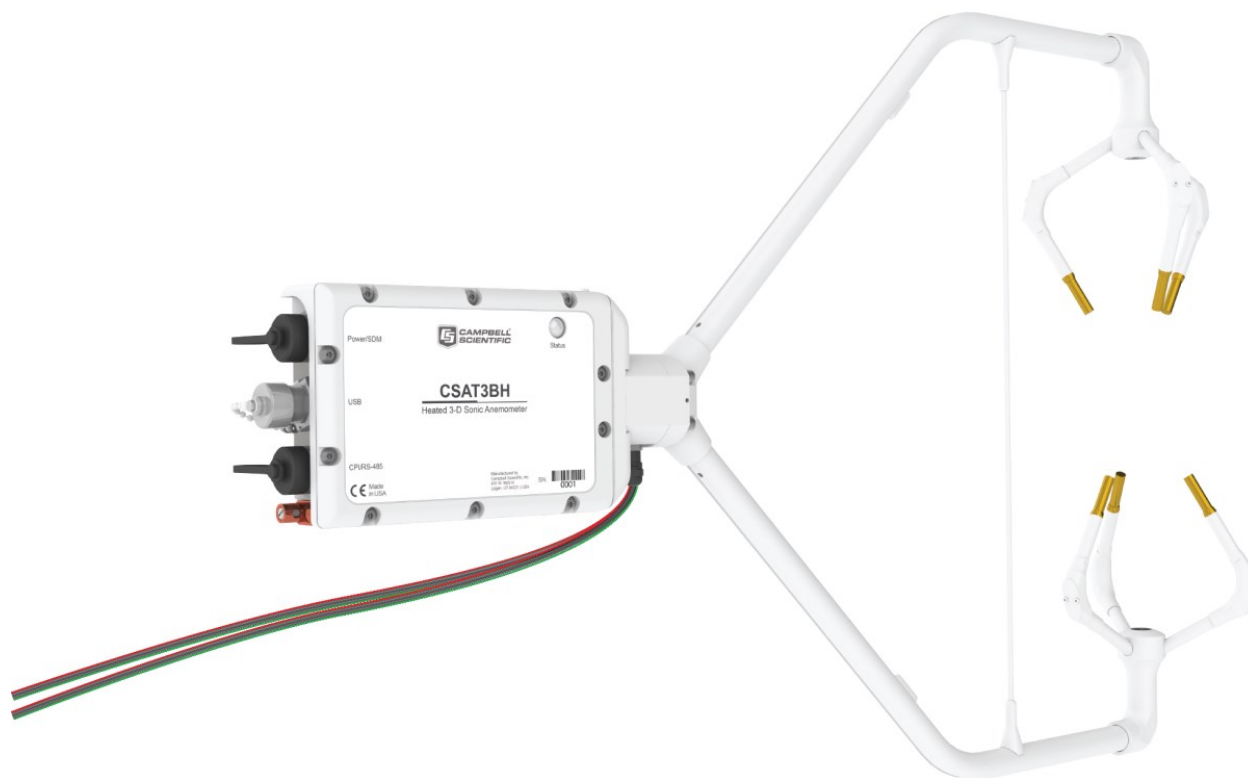


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1. Introduction

The CSAT3BH is a heated version of the CSAT3B 3-D sonic anemometer with integrated electronics. This instrument measures sonic temperature and wind speed in three dimensions. The ultrasonic transducers, chassis, and strut can be heated to keep ice from accumulating on the instrument. This new heating feature gives the CSAT3BH an advantage over traditional anemometers and sonic anemometers because data loss will be significantly reduced in areas that experience frozen precipitation. The CSAT3BH features variable power for the heating elements by only delivering power to the heaters when needed, as opposed to the common method of providing two-way heating (on or off). Further, real-time data flags are generated when the heaters are turned on, which is critical to post-processing the data.

The CSAT3BH can measure average horizontal wind speed and direction, or turbulent fluctuations of horizontal and vertical wind, and sonic temperature. Further, momentum flux and sensible heat flux can be calculated from the turbulent wind and sonic temperature fluctuations. Latent and sensible heat flux and gas fluxes may be determined by computing the covariance between vertical wind measured by the CSAT3BH and scalar quantities measured by other appropriate sensors.

Before attempting to use or install the CSAT3BH, please review:

- [Precautions](#) (p. 1)
- [Initial inspection](#) (p. 2)

2. Precautions

- READ AND UNDERSTAND the [Safety](#) section at the back of this manual.
- CAUTION
 - Voltage input must be within a range of 22 to 32 VDC for the CSAT3H heater controller and 9.5 to 32 VDC into the power connector on the CSAT3BH electronics.
 - The CSAT3BH head should be handled by holding the block at the back of the sensor. Handling it by the arms or transducers could cause geometric deformation, which degrades the measurements.

- The transducer faces are fragile. Avoid scratching or rubbing the surface of the transducer.
- Grounding the CSAT3BH is critical. Proper grounding to earth will ensure maximum electrostatic discharge (ESD) and lightning protection and improve measurement accuracy. The data logger, CSAT3H heater controller enclosure, and CSAT3BH electronics should all be grounded to the same grounding rod.
- During winter, remove wicks from the transducers to prevent ice from melting and collecting on the wicks, which could lead to re-freezing and ice buildup.
- Avoid opening the heater controller box because of unprotected electronics that are vulnerable to ESD damage.
- IMPORTANT
 - Install USB drivers and *Device Configuration Utility* before attaching the sensor to a computer.

3. Initial inspection

Upon receipt of the CSAT3BH, inspect the packaging and contents for damage. File any damage claims with the shipping company. Contact Campbell Scientific to facilitate repair or replacement.

Immediately check package contents against shipping documentation. Thoroughly check all packaging material for product that may be trapped inside. Contact Campbell Scientific about any discrepancies. Model numbers are found on each product. On cables, the model number is often found at the connection end of the cable. Check that correct lengths of cables are received.

The CSAT3BH ships with:

- Temp/RH sensor with radiation shield
- CSAT3BH replacement desiccant
- CSAT3BH foam case set
- CSAT3H heater controller box
- CM250 leveling mounting kit
- USB data cable

Cables for the CSAT3BH, although not included in the standard package, are specified at the time of order and are shipped with the CSAT3BH:

- CSAT3HCBL3-L
- RS-485 cable (either CSAT3HCBL1-L or CSAT3HCBL2)
- Either CSAT3BCBL1-L or CSAT3BCBL2-L and CSAT3BCBL3-L

4. Overview

The CSAT3BH is an ultrasonic anemometer for measuring sonic temperature and wind speed in three dimensions. It is often used for studies of turbulence and flux measurements, where turbulent fluctuations of wind speed and sonic temperature must be measured at high frequencies (at 10 Hz, for example).

From the turbulent wind fluctuations, momentum flux can be calculated. The covariance of vertical wind and sonic temperature yields sonic sensible heat flux. By finding the covariance between vertical wind and scalar measurements made by other fast-response sensors, such as fine-wire thermocouples or gas analyzers, other fluxes can be calculated. For example, sensible and latent heat fluxes, carbon dioxide flux, and other trace gas fluxes can all be measured by combining the CSAT3BH with other sensors.

The CSAT3BH can communicate measurements using SDM (Synchronous Device for Measurements), USB, RS-485, and CPI (CAN Peripheral Interface) communications. For optimal synchronization with other fast-response sensors for applications such as eddy covariance, Campbell Scientific recommends using SDM or CPI communications with an appropriate Campbell Scientific data logger.

The CSAT3BH is a heated version of the CSAT3B, with the same measurement specifications. Developed for use in cold environments that typically experience ice buildup on sensors, the CSAT3BH is designed to prevent ice from accumulating on the sensor in order to avoid prolonged periods of data loss.

The CSAT3BH is paired with a temperature and relative humidity probe that is used to determine when the heaters need to be operating. The information from the temperature and relative humidity probe is processed within the CSAT3H heater controller box, dictating operation of the heaters. Additionally, temperature measurements are made throughout the body of the sonic anemometer to determine the temperature change of the sensor as a result of the heaters. This information is delivered to the controller box as well.

4.1 Features

The CSAT3BH offers the following key features:

- Integrated electronics provide easy mounting of a single piece of hardware
- Integrated inclinometer
- High-precision measurements ideal for turbulence and eddy-covariance studies
- An improved design with a thin, aerodynamic support strut close to the ends of the sensor arms, creating greater rigidity and improved accuracy of sonic temperature
- Support of data logger sampling at any frequency between 1 and 100 Hz
- CPI communications for more robust and higher bandwidth measurements
- Multiple communication options, including SDM, CPI, USB, and RS-485
- Internal temperature and humidity measurements with easily replaced desiccant
- Version 5 algorithm for calculating data outputs; combines the signal sensitivity of version 3 with the rain performance of version 4
- Options to filter high frequencies for applications requiring analysis of non-aliased spectra
- Two controlled heating zones that automatically provide enough heat to keep the sensor free of ice in areas that matter most
 - Arms and strut
 - Transducer fingers
- Diagnostics to determine heat activity to allow for Quality Assurance/Quality Control of data as well as reports of how much power is used to control the heaters
- CSAT3BH body temperature measurements from thermistors near the transducers, strut, and arms to help track the heater performance
- Streamlined heater integration to preserve sonic aerodynamics and ensure proper operation

4.2 Sensor components

The CSAT3BH consists of several components. Some components come standard with every CSAT3BH; others are accessories that must be ordered separately. Some common accessories, such as cables, are required to operate a CSAT3BH.

4.2.1 Standard components

Standard components are items that are included or shipped with the CSAT3BH. The following sections describe these items.

4.2.1.1 CSAT3H heater controller box

The CSAT3H heater controller box collects temperature and relative humidity data from the temp/RH probe (see [Temperature/relative humidity sensor and shield](#) (p. 5)) as well as body temperature measurements from the sonic anemometer. These measurements are used for determining when the heaters are turned on or off, as well as how much power should be supplied to the heaters to prevent ice accumulation and to prevent damage to the instrument from overheating, in the case of a fault. The CSAT3H heater controller box is shown in [FIGURE 4-1](#) (p. 5). Connectors at the bottom of the CSAT3H heater controller box are shown in [FIGURE 6-12](#) (p. 41) and described in [Controller box connections](#) (p. 42).



FIGURE 4-1. CSAT3H heater controller box

4.2.1.2 Temperature/relative humidity sensor and shield

A temperature and relative humidity sensor (shown in [FIGURE 4-2](#) (p. 6)) with a 6-plate gill radiation shield comes with the CSAT3BH. This sensor provides important temperature and relative humidity data that is used within the heating algorithm to determine when the heaters are turned on or off. This sensor should be mounted in such a way that it is level with the sonic

anemometer but doesn't interfere with the flow into the measurement path. A U-bolt, 1/2-in screws, and washers come with the temp/RH probe for mounting the radiation shield containing the sensor.



FIGURE 4-2. Temperature/relative humidity sensor and shield, with mounting hardware

4.2.1.3 CM250 leveling mounting kit

The CM250 leveling mounting kit is shipped with the CSAT3BH and comes with an adapter (FIGURE 4-3 (p. 6)) that facilitates mounting a CSAT3BH at the end of a 3.33 cm (1.31 in) OD crossarm or pipe. The kit includes a captive 3/8-in bolt that screws into the bottom of the CSAT3BH block, and a 3/16-in Allen wrench to tighten the adapter on the pipe.

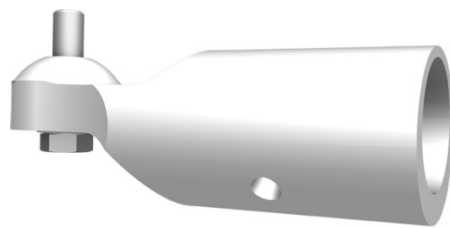


FIGURE 4-3. CM250 mount

4.2.1.4 USB data cable

The USB data cable is a 5 m (16 ft) USB cable (FIGURE 4-4 (p. 7)) included with the CSAT3BH. One end has a standard type-A pin connector to connect to a computer, and the opposite end has a mini-B pin connector, which connects to the USB port on either the back of the CSAT3BH block or the bottom of the CSAT3H heater controller box. The mini-B pin connector is rated to Ingress Protection 68 (IP68) to exclude fine dust and water. When connected with the cable, **Device**

Configuration Utility allows the user to view or set settings, send a new operating system to the CSAT3BH, or view real-time measurements. It is also possible to use this cable to collect data with a computer in unprompted USB mode. [Communications](#) (p. 44) provides additional information.



FIGURE 4-4. USB data cable

4.2.2 Optional components

4.2.2.1 Sonic environment option

If the CSAT3BH will be located in harsh environments, such as marine or heavily fertilized locations, coated transducers can be purchased as an option to help prevent corrosion.

4.2.2.2 Sonic carrying case

A large, hard plastic Pelican™ carrying case is available for the CSAT3BH. It is watertight and highly durable. This case is recommended for transporting and storing the CSAT3BH. It includes a set of foam inserts that hold the CSAT3BH in a protected position while providing space for additional components.

If the sonic carrying case option is not selected, the CSAT3BH will be shipped in a large cardboard box. The same set of foam inserts used in the sonic carrying case is used in the cardboard box to securely hold the CSAT3BH.

NOTE:

With the cardboard box shipment option, keeping the foam inserts and box is highly recommended. When returning a CSAT3BH for factory recalibration or repair, it is important to ship the unit with the foam inserts provided from the factory.

4.2.3 Common accessories

Common accessories for the CSAT3BH include cables as well as other equipment to make sensible heat flux measurements. A fine-wire thermocouple is an example of an additional sensor often used with a CSAT3BH. Descriptions of cables and other common accessories are described in greater detail in the following sections.

4.2.3.1 Power and communications cables

Cables required for the CSAT3BH to function must be ordered with the CSAT3BH. Cables are required for both the anemometer itself and the CSAT3H controller box.

The anemometer requires a communication cable that transfers the data to the data logger. Communication can either be made via SDM or CPI. If using SDM, an additional power cable is not required because power can be transferred.

The CSAT3H heater controller box supplies power to the heaters and communicates with the main data logger that is used to collect the wind and sonic temperature data from the anemometer. Therefore, a power cable going from the 22 to 32 VDC power supply to the CSAT3H controller box is needed. An RS-485 cable that can establish a communication channel between the controller and main data logger or computer is also required.

Campbell Scientific uses a system for naming cables that provides details of a cable and some information about its use.

- The “-L” in a cable model name is an option that denotes a user-specified length of cable in feet.
- The “-PT” is a cable option that specifies one end of the cable to have pigtail wires for wiring to a power source, data logger terminals, or a wiring bus. The other end has an M16 connector for connecting to the corresponding port at the back of the CSAT3BH block.
- The “-MC” option designates an M16 connector on both ends of the cable and is used to daisy-chain several CSAT3BH instruments together in series.

NOTE:

Daisy-chaining requires ordering a splitter (see [Power/SDM splitter](#) (p. 13) and [CPI/RS-485 splitter](#) (p. 14)) for each CSAT3BH in series except the terminal one. While looking similar, two different splitters are required when daisy-chaining for Power/SDM or for CPI. What differentiates the splitters is the number of pin channels they have, making it impossible to use the incorrect splitter with a cable. The Power/SDM splitter has six pin connectors, and the CPI/RS-485 splitter has eight.

- The “-RJ” option has an RJ-45 connector on one end for connecting directly to the CPI port on a data logger such as the CR6 or to a CPI port on the HUB-CPI if a network of several CPI devices is being installed in a star topology. The other end of the cable has an M16 connector for connecting to the CSAT3BH block.

The following paragraphs outline the types of cables needed for a specific communications mode. For information on maximum cable lengths, refer to the specifications in [Communications](#) (p. 44).

Power/SDM cable (CSAT3BCBL1)

To use SDM communications to collect data from a CSAT3BH with a data logger, the CSAT3BCBL1-L-PT or CSAT3BCBL1-L-MC should be ordered. [FIGURE 4-5](#) (p. 9) shows the two versions. This cable transmits both power and SDM communication signals.

NOTE:

To collect data through another means (such as CPI, RS-485, or USB), the CSAT3BCBL1 Power/SDM cable may still be used to provide power to the CSAT3BH, in which case the SDM wires should be left unwired to any ports on the data logger.

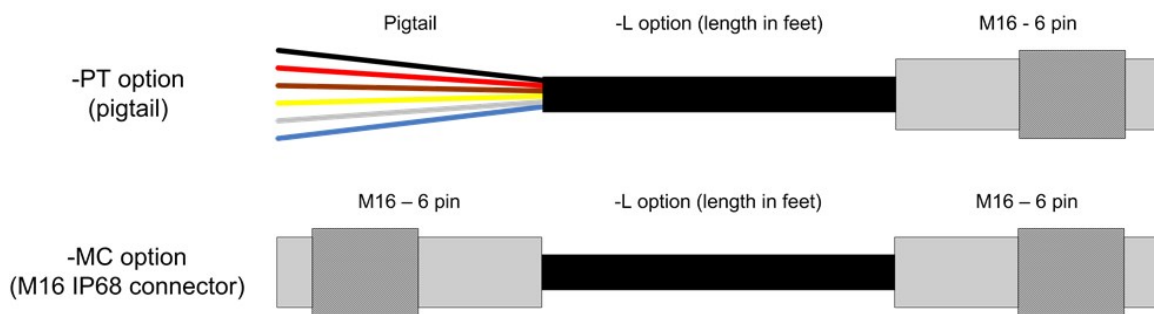


FIGURE 4-5. Options for CSAT3BCBL1 Power/SDM cable

Power cable (CSAT3BCBL2)

To use CPI, RS-485, or USB communications to collect data from a CSAT3BH, the CSAT3BCBL2-L-PT or CSAT3BCBL2-L-MC should be ordered to provide power to the sensor. A second cable to transmit the communications is also required (for example, a CSAT3BCBL3 CPI/RS-485 cable for CPI or RS-485, or a USB data cable).

For installations with long cable lengths, the CSAT3BCBL2 is preferred over the CSAT3BCBL1 for providing power due to the heavier gauge wires that reduce voltage drop over long distances. Allowed length is 1 to 550 feet. Although the maximum cable length is 550 feet, users requiring a cable length of 401 to 550 feet should use a 24 V power supply.

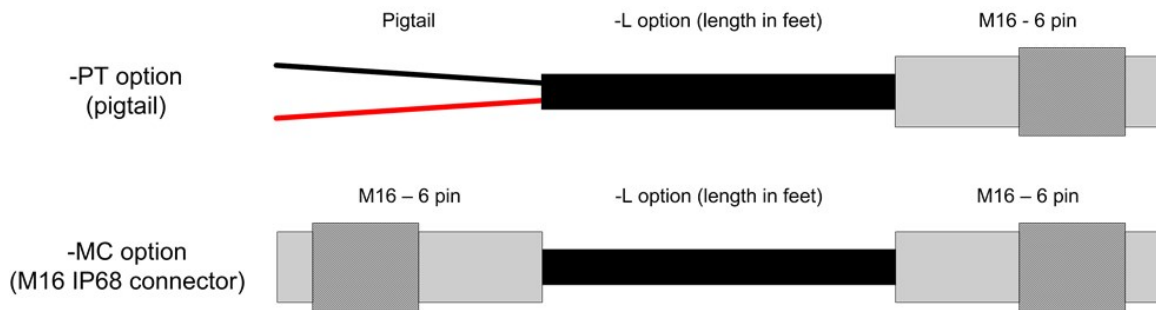


FIGURE 4-6. Options for CSAT3BCBL2 power cable

CPI/RS-485 cable (CSAT3BCBL3)

To use CPI or RS-485 communications to collect data from a CSAT3B, the CSAT3BCBL3-L-PT, CSAT3BCBL3-L-RJ, or CSAT3BCBL3-L-MC, should be ordered along with a cable to provide power to the sensor (for example, either the CSAT3BCBL1 or CSAT3BCBL2).

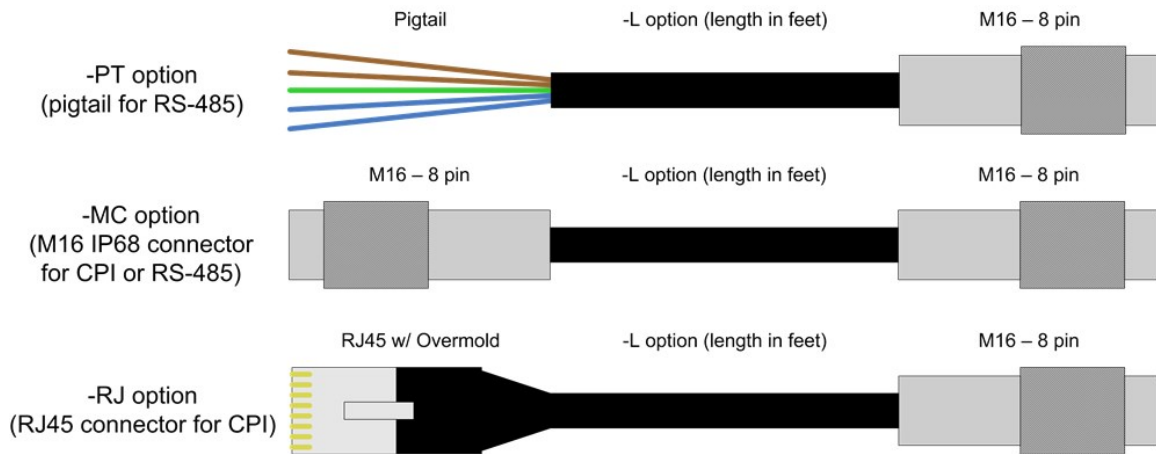


FIGURE 4-7. Options for cabling CPI or RS-485 communications

CSAT3H heater controller RS-485 TX/RX cable (CSAT3HCBL1-L)

Important heater diagnostic information is collected by the CSAT3H heater controller box. To transfer this information from the controller box to the main data logger for storage, a CSAT3HCBL1-L cable should be ordered. One end of the cable is a 3-pin IP67 military connector that connects to the CSAT3H heater controller box; the other end is a pigtail with brown, white, and black wires that connects to the main data logger. Allowed lengths of this cable are between 1 and 300 ft.

CSAT3H heater controller RS-485 RX cable (CSAT3HCBL2)

If the sonic anemometer is using a computer or a data acquisition system other than a Campbell Scientific data logger to collect data from the CSAT3H heater controller box, then a CSAT3HCBL2

should be ordered to connect the CSAT3H heater controller box to the other data acquisition system. One end of the cable is a 3-pin IP67 military connector that connects to the controller box; the other end is a pigtail with brown, white, and black wires that connects to the computer. This cable comes at a set length of 15 ft.

CSAT3H heater controller power cable (CSAT3HCBL3-L)

A CSAT3HCBL3-L must be ordered to provide 24 VDC power to the CSAT3H heater controller box. This cable is ordered to a specified length ranging from 1 to 30 feet. The cable has a 2-pin IP67 military connector on the end that connects to the controller box, and a red- and black-wired pigtail that connects to the 24 VDC power supply. Because the length of this cable has a shorter maximum length than the CSAT3HCBL1-L, it is recommended that the CSAT3H controller box be located close to the 24 VDC power supply.

4.2.3.2 FW05 thermocouple

The FW05 is a Type E thermocouple with a 0.0127 mm (0.0005 in) diameter (FIGURE 4-8 (p. 11)). The thermocouple measures atmospheric temperature fluctuations and may be used with the CSAT3BH to directly calculate sensible heat flux. Larger size fine-wire thermocouples, such as the FW1 and FW3, which are more robust but have slower response times, may also be used with the CSAT3BH.



FIGURE 4-8. FW05 thermocouple

NOTE:

Users requiring fine-wire thermocouples for atmospheric temperature measurements should consider their data logger choice. The CR6 data logger is not optimal for taking fine-wire thermocouple measurements. For help in choosing the best data logger when fine-wire thermocouples are required, contact Campbell Scientific.

4.2.3.3 FWC-L cable

The FWC-L is a cable with connector that is compatible with the connector on a FW05, FW1, or FW3 fine-wire thermocouple. The other end of the cable has pigtail wires to wire to a pair of

differential voltage terminals on a data logger. The -L denotes the length of cable in feet, which can be designated at the time of ordering.

4.2.3.4 Thermocouple cover

The thermocouple (TC) cover is a white, metal thermocouple cover that is placed over the connectors of the FW05 and the FWC-L cable. It is used to mount the connectors to the side of the CSAT3BH block. It also minimizes temperature gradients across the connectors.

4.2.3.5 Thermocouple cover backplate

The CSAT3BH fine-wire thermocouple cover backplate attaches to the CSAT3BH block and is used to cover the back side of the TC cover.

NOTE:

The backplate is required for the CSAT3BH but not for other Campbell Scientific sonic anemometers. In previous models, the back side of the TC cover is covered by the sensor block.

4.2.3.6 FW/ENC thermocouple carrying case

The FW/ENC is a small case (FIGURE 4-9 (p. 12)) that is used for storing up to four fine-wire thermocouples. Due to the fragile nature of the FW05 thermocouple, it should always be stored in an FW/ENC when not in use. Ordering at least a set of four FW05 thermocouples for every CSAT3BH is recommended, as the FW05 will break during normal wear and tear in the field.

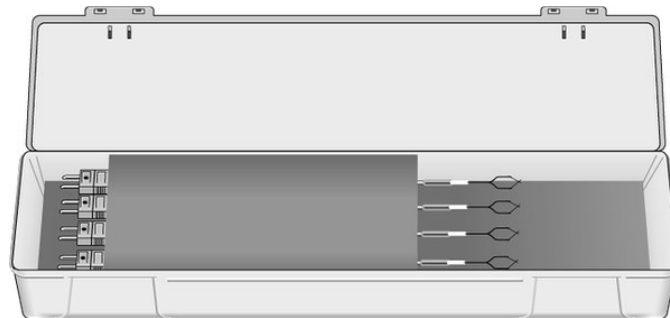


FIGURE 4-9. FW/ENC for storing fragile thermocouples


4.2.4 Other accessories

The other accessories available for the CSAT3BH are used when combining multiple CSAT3BH units into a network of sensors, the data from which is collected by a single data logger.

Networks of CSAT3BHs using SDM or CPI communications may be configured in one of three different configurations:

- In a series using a daisy-chain topology
- In parallel using a star topology
- In a combination of daisy-chain and star topologies

When designing an SDM or CPI network, careful attention should be given to not exceed a total network cable length that will excessively attenuate the sensor signals. The exact total length will depend on factors such as sample rate and topology, but in general the maximum cable lengths (given in [Communications](#) (p. 44)) for each communication type and data rate should be followed.

Because CPI communications can support longer network cable lengths, it is generally recommended as the communication method for sensor networks. For more detailed information on network topologies and limits on cable lengths for CPI networks, see the white paper titled *Designing Physical Network Layouts for the CPI Bus*, available at www.campbellsci.com .

4.2.4.1 Power/SDM splitter

The Power/SDM splitter, shown in [FIGURE 4-10](#) (p. 13), has three 6-pin M16 connectors. This splitter allows for connection at the Power/SDM port on the back of the CSAT3BH block to two CSAT3BCBL1 or CSAT3BCBL2 cables. The splitter is IP68 rated, meaning it is dustproof and watertight. It is used for daisy-chaining multiple CSAT3BHs in series. A Power/SDM splitter is required for each CSAT3BH in the daisy chain (regardless of communication method used), except for the terminal one.



FIGURE 4-10. CSAT3BH Power/SDM splitter (showing pin configuration)

4.2.4.2 CPI/RS-485 splitter

The CPI/RS-485 splitter, shown in [FIGURE 4-11](#) (p. 14), has three 8-pin M16 connectors. This splitter allows for connection at the CPI/RS-485 port on the back of the CSAT3BH block to two CSAT3BCBL3 cables. The splitter is IP68 rated. It is used for daisy-chaining multiple CSAT3BHs in series that use CPI or RS-485 communications. A splitter is required for each CSAT3BH in the daisy chain, except for the terminal one. For a daisy chain of CSAT3BHs using SDM communications, the CPI/RS-485 splitter is not needed; in this case, only the Power/SDM splitter (see [Power/SDM splitter](#) (p. 13)) is needed.

NOTE:

The Power/SDM and CPI/RS-485 splitters look similar; however, they differ in number of pins and are not interchangeable.



FIGURE 4-11. CSAT3BH CPI/RS-485 splitter (showing pin configuration)

Transient voltage drop is commonly caused by the large series inductance introduced by long power cables, multiple CSAT3BHs connected by splitters, or a combination. Because the measurements are synchronized, multiple CSAT3BHs connected to the same power cable each draws a pulse of current at the same moment. This has a cumulative effect on the voltage drop. If the voltage drop is sufficiently large, then the low-voltage detection circuit inside the CSAT3BH sensor can be tripped, which forces the device to reset. A power cable compensation plug for the CSAT3BH ([FIGURE 4-12](#) (p. 15)) is needed if voltage drop creates problems. The plug is compatible with all CSAT3BHs. The plug should be placed on the final Power/SDM splitter in the CSAT3BH daisy chain, farthest from the power supply.



FIGURE 4-12. CSAT3BH power cable compensation plug

The primary indicator of low voltage is in the diagnostic flags returned by the CSAT3BH to the data logger. Flag number 32 (0x0020) indicates detection of a low-voltage condition. If the instrument returns flag 32, first measure the power source voltage and ensure that its DC value meets specifications. If that value is appropriate, the voltage at the far end of the cable should be checked. This must be tested under load so a splitter at the end of the cable will be required to measure the terminal voltage. These two tests will eliminate the DC voltage as the source of the problem. Any DC voltage below 12 V at the sensor would be suspect for susceptibility to droop. In larger systems, even DC voltages of 13 to 15 V can still experience enough droop to trigger the detection under the right conditions. Power systems of 24 V are very unlikely to experience enough droop to observe this problem. If the DC case checks out but the flag is still observed, then the system would probably benefit from the addition of a power compensation plug (FIGURE 4-12 (p. 15)).

4.2.4.3 HUB-SDM8

The HUB-SDM8 (shown in FIGURE 4-13 (p. 16)) allows up to six SDM devices (typically, one data logger and multiple SDM sensors) to be connected in parallel. In the case of the CSAT3BH, up to five CSAT3BHs, or CSAT3BH daisy chains using CSAT3BCBL1 cables, may be connected to the HUB-SDM8. In cases where multiple CSAT3BHs are installed some distance from the data logger, the HUB-SDM8 can be placed near the CSAT3BHs with a single SDM cable extended from the hub to the data logger. This decreases the total network cable length, which limits signal attenuation.

The HUB-SDM8 has eight terminal strips and features spring-loaded guillotine terminals for easy wiring. It comes in a watertight enclosure and includes a U-bolt for mounting to a vertical pipe or mast. An SDM cable (CABLE5CBL-L; see SDM cable CABLE5CBL-L (p. 16)) should be ordered to connect the HUB-SDM8 to a data logger and a power supply.



FIGURE 4-13. HUB-SDM8 for multiple CSAT3BH connections with SDM communications

4.2.4.4 SDM cable CABLE5CBL-L

The CABLE5CBL-L is used to connect the power and SDM connection from a HUB-SDM8 to the power and SDM connections on a power source and data logger.

CABLE5CBL-L is a 22 AWG, 5-conductor cable with a Santoprene jacket and aluminum Mylar shield. By default, the conductors are stripped and tinned.

4.2.4.5 HUB-CPI

The 8-channel RJ45 HUB-CPI allows up to eight CPI devices to be connected in parallel. Up to seven CSAT3BHs, or CSAT3BH daisy chains using CSAT3BCBL3 cables, may be connected in parallel to the HUB-CPI. The remaining port may be used with a CAT5e or CAT6 Ethernet cable (see [CAT6 Ethernet cable](#) (p. 17)) to connect the HUB-CPI to the CPI port on a data logger such as the CR6.

The HUB-CPI (shown in [FIGURE 4-14](#) (p. 17)) is not weatherproof and should be housed in an enclosure, typically alongside the data logger.

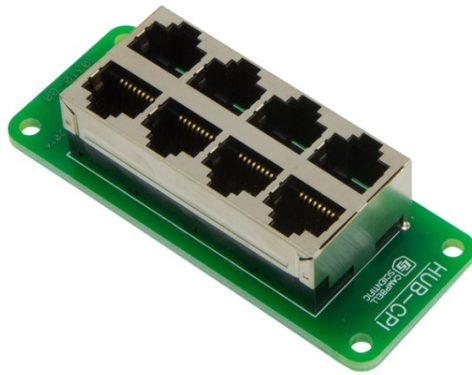


FIGURE 4-14. HUB-CPI for multiple CSAT3BH connections to CPI communications

4.2.4.6 CAT6 Ethernet cable

The CAT6 Ethernet cable is a 61 cm (2 ft) unshielded CAT6 network cable with RJ45 connectors (FIGURE 4-15 (p. 17)). Typically, it connects the HUB-CPI to the CPI port on a data logger such as the CR6.



FIGURE 4-15. CAT6 Ethernet cable

5. Specifications

The CSAT3BH measures wind speed and the speed of sound along the three non-orthogonal sonic axes. The wind speeds are then transformed into the orthogonal wind components u_x , u_y , and u_z , and are referenced to the anemometer head. The reported sonic temperature (T_s) is the average between the temperatures computed for the three non-orthogonal sonic axes.

The vector component of the wind that is normal to each sonic axis (such as a crosswind) leads to a measurement error that is corrected online by the CSAT3BH before the wind speed is

transformed into orthogonal coordinates. Because of this correction, it is not necessary to apply the speed of sound correction described by Liu, Peter, and Foken (2001; see [References](#) (p. 91)).

The CSAT3BH has several operating modes to suit different applications. The anemometer can be configured to make a single measurement per data logger trigger, or it can operate in a self-triggered mode. When self-triggering, the CSAT3BH will make measurements at a high rate, apply an optional user-selectable bandwidth filter, and provide the latest output upon receiving an output prompt. An output prompt may come from the data logger, or in the case of unprompted output mode (such as computer data collection), the output is prompted by the CSAT3BH itself. The default operating mode of the CSAT3BH is to make measurements when triggered by a data logger (SDM or CPI), which does not apply any low-pass (high-cut) filtering. See [Communications](#) (p. 44) for a list of all default settings, and see [Operating modes](#) (p. 65) for more information on modes.

5.1 Measurements

Operating temperature

Standard: -40 to 50 °C

Wind accuracy (-40 to 50 °C, wind speed < 30 m·s⁻¹, azimuth angles between ± 170 °C)

Offset error

u_x : ± 8 cm·s⁻¹ max

u_y : ± 8 cm·s⁻¹ max

u_z : ± 4 cm·s⁻¹ max

Gain error

Wind vector $\pm 5^\circ$ of horizontal: $\pm 2\%$ of reading max

Wind vector $\pm 10^\circ$ of horizontal: $\pm 3\%$ of reading max

Wind vector $\pm 20^\circ$ of horizontal: $\pm 6\%$ of reading max

Wind resolution

u_x : 1.0 mm·s⁻¹ RMS

u_y : 1.0 mm·s⁻¹ RMS

u_z : 0.5 mm·s⁻¹ RMS

Wind full scale range: ± 65 m·s⁻¹

Sonic temperature resolution: ± 0.002 °C RMS at 25 °C

Sonic temperature reporting range:	-40 to 50 °C
Measurement rates	
Data logger triggered:	1 to 100 Hz
Unprompted output (to computer):	10, 20, 50, or 100 Hz
Internal self-trigger rate:	100 Hz
Measurement delay	
Data logger triggered (no filter):	1 trigger period (1 scan interval)
Unprompted output (no filter):	10 ms
Filtered output (data logger prompted or unprompted to computer):	795 ms with 5 Hz bandwidth filter 395 ms with 10 Hz bandwidth filter 155 ms with 25 Hz bandwidth filter
Filter bandwidths:	5, 10, or 25 Hz
Internal monitor measurements	
Update rate:	2 Hz
Inclinometer accuracy:	± 1°
Relative humidity accuracy:	± 7% over 0 to 10% range ± 3% over 10 to 90% range ± 7% over 90 to 100% range
Board temperature accuracy:	± 2 °C
Temperature/relative humidity probe accuracy:	± 0.3 °C/± 3%
Chassis thermistor accuracy:	± 1 °C

5.2 Communications

SDM: Used for data logger-based data acquisition.

Bit period:	10 µs to 1 ms
Cable length: ^{1/}	7.6 m (25 ft) max @ 10 µs bit period 76 m (250 ft) max @ 1 ms bit period
Address range:	1 to 14

Bus clocks per sample: ~200

CPI: Used for data logger-based data acquisition^{1/}.

Baud rate: 50 kbps to 1 Mbps

Cable length: 15 m (50 ft) max @ 1 Mbps
122 m (400 ft) max @ 250 kbps
853 m (2800 ft) max @ 50 kbps

Address range: 1 to 120

Bus clocks per sample: ~300

RS-485: Used for anemometer configuration or computer-based data acquisition. (Same for controller box to data logger except a baud rate of only 115.2 kbps and use of the 305 m maximum cable length.)

Baud rate: 9.6 kbps to 115.2 kbps

Cable length: 305 m (1000 ft) max @ 115.2 kbps
610 m (2000 ft) max @ 9.6 kbps

Bus clocks per sample: ~500 (ASCII formatted)

USB: Used for anemometer configuration or computer-based data acquisition.

Connection speed: USB 2.0 full speed 12 Mbps

Cable length: 5 m max

^{1/} For additional details, refer to Campbell Scientific whitepaper "Designing Physical Network Layouts for the CPI Bus"

5.3 Power requirements

Anemometer voltage requirement: 9.5 to 32 VDC

Current requirement (10 Hz measurement rate)

Current @ 12 VDC: 110 mA

Current @ 24 VDC: 65 mA

Current requirement (100 Hz measurement rate)

Current @ 12 VDC: 145 mA

Current @ 24 VDC: 80 mA

Heaters

Heaters @ 24 VDC: 6.2 A

Arms and strut @ 24 VDC:	0.74 A nominal; 2.46 A at max heating
Transducer fingers @ 24 VDC:	1.13 A nominal; 3.75 A at max heating
Total system power @ 24 VDC:	1.86 A nominal; 6.2 A at max heating
Current requirement (controller) heaters off (quiescent) @ 24 VDC:	30 mA

5.4 Physical description

5.4.1 Sonic anemometer dimensions

Overall:	63.1 cm (24.8 in) length 43.3 cm (17.0 in) height 12.3 cm (4.9 in) width
Measurement path:	10.0 cm (3.9 in) vertical 5.8 cm (2.3 in) horizontal
Transducer angle:	60 degrees from horizontal
Transducer diameter:	0.64 cm (0.25 in)
Transducer mounting diameter:	0.84 cm (0.33 in)
Support arm diameter:	1.59 cm (0.63 in)
Cardboard box with foam:	73.7 x 45.7 x 25.4 cm (29 x 18 x 10 in)
Carrying case with foam:	79.5 x 51.8 x 31 cm (31.3 x 20.4 x 12.2 in)
Weight	
Head:	1.9 kg (4.2 lb)
Including cardboard box option:	5.7 kg (12.6 lb)
Including carrying case option:	13.8 kg (30.5 lb)
Shipping (both cardboard and carrying cases options are shipped within a second box)	
Cardboard box option	
Weight:	9.1 kg (20.0 lb)
Dimensions:	91 x 51 x 41 cm (36 x 20 x 16 in)
Carrying case option	
Weight:	16.3 (36.0 lb)
Dimensions:	81 x 66 x 43 cm (32 x 26 x 17 in)

5.4.2 CSAT3H heater controller box dimensions

Overall: 26.7 cm (10.5 in) length
15.7 cm (6.2 in) height
21.8 cm (8.6 in) width

Weight: 1.9 kg (4.2 lb)

Shipping box

Weight (with controller): 3.3 kg (7.3 lb)

Dimensions: 41 x 41 x 20 cm (16 x 16 x 8 in)

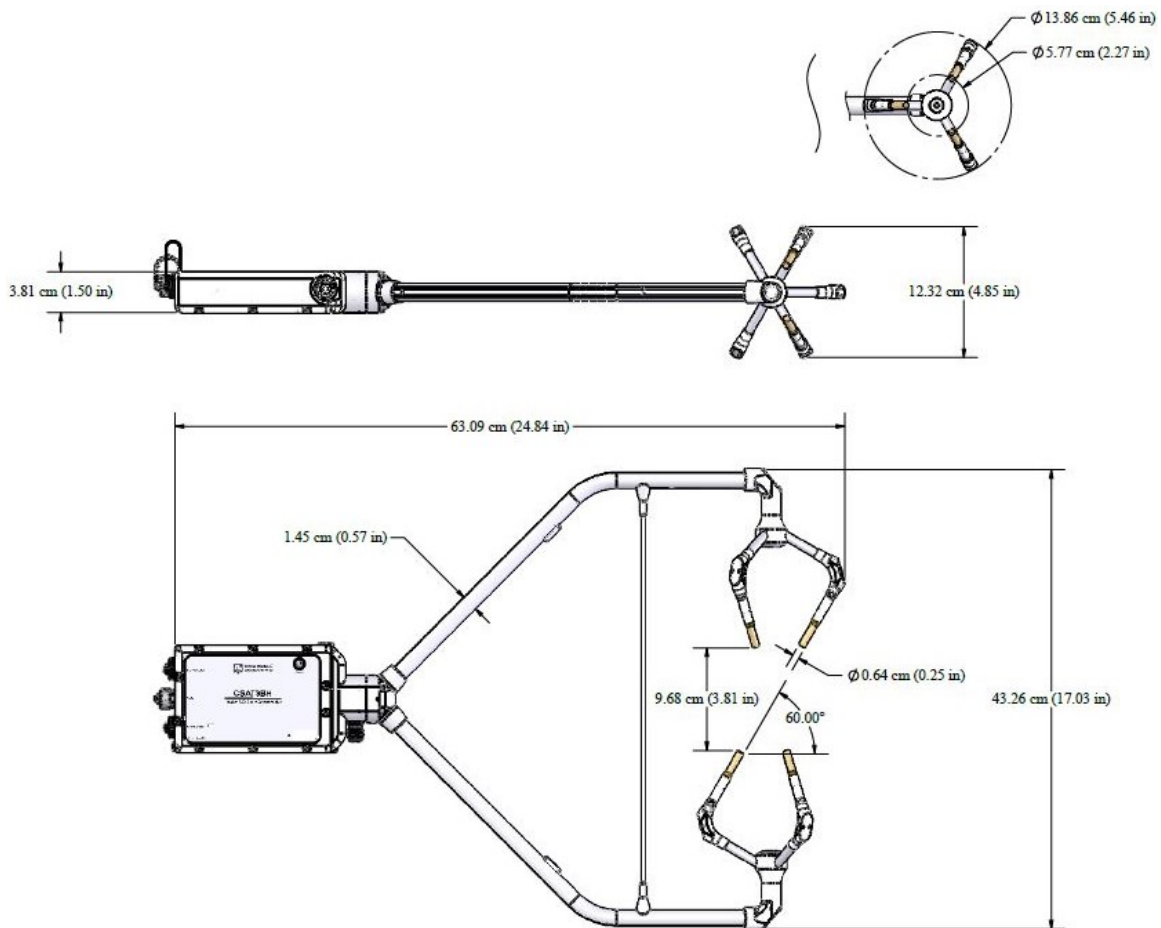


FIGURE 5-1. Dimensions of CSAT3BH

6. Installation

6.1 Introduction

The CSAT3BH includes the CSAT3BH sonic anemometer, CSAT3H heater controller box, temp/RH sensor with 6-plate gill radiation shield mounting hardware, and USB cables to connect the CSAT3BH to the CSAT3H heater controller box. All other cables are selected and purchased separately for type of communication and size requirements of the site setting.

The customer will provide a data logger capable of RS-485 communications, such as a CR6 or CR1000X. If a data logger with RS-485 is not available, an MD485 running in transparent mode may be purchased to convert from RS-232 to RS-485 communications. RS-485 communications between the controller and data logger are a requirement to pass environmental, diagnostic, and operational variables in the CSAT3BH. If the communication link is not operating properly, the controller will not turn on, and the heater will not operate.

The heater controller requires a reliable 22 to 32 VDC input voltage and up to 6.2 A (~150 W) for proper operation of the heaters. The data logger and CSAT3BH require 12 VDC for operation.

6.2 Site considerations

The heater and power cables between the CSAT3BH and CSAT3H heater controller box are a fixed 15-ft length; therefore, considerations should be made when mounting the controller box within the proximity of the CSAT3BH sensor. Similarly, the CSAT3H heater controller box must be within 30 ft of the 22 to 32 VDC power supply, as the power cable is 30 ft long. The CSAT3BCBL1-L that enables communication between the controller box and the data logger can be up to 300 ft long, allowing the data logger to be up to 300 ft from the controller box.

If the CSAT3BH is to be used in a marine environment or in an environment where it is exposed to corrosive chemicals (for example, the sulfur-containing compounds in viticulture), attempt to mount the CSAT3BH in a way that reduces exposure of the sonic transducers to saltwater or corrosive chemicals. In marine or viticulture environments, the sonic transducers are expected to age more quickly and require replacement sooner than a unit deployed in an inland, chemical-free environment. If the CSAT3BH is intended to be located in either of these environments, coated transducers, which help prevent corrosion, can be purchased as an option.

Campbell Scientific recommends that the CSAT3BH and data acquisition system be set up in a laboratory setting before field installation. This provides an opportunity to verify that settings and programs are correct in a controlled environment. Prior to setup, the user needs to know


information about the desired sensor settings and orienting, mounting, and leveling the CSAT3BH, which is covered in the following sections.

6.3 Settings

Prior to installation, the CSAT3BH settings should be verified in a lab setting to make sure all parts are accounted for and the system is functioning properly.

6.3.1 Verify CSAT3BH settings

Verify the CSAT3BH settings in a laboratory through the following steps:

1. Provide power to the CSAT3BH by connecting the M16 connector of either a CSAT3BCBL1 or CSAT3BCBL2 to the **Power/SDM** port on the back of the CSAT3BH block. The other end of this cable will have red and black wires that should be connected to a 9.5 to 32 VDC power source. (In the case of the CSAT3BCBL1, the other wires need not be connected.)
2. Connect the circular connector on the USB data cable included with the CSAT3BH to the port labelled **USB** on the back of the CSAT3B block. Connect the other end of the cable to a USB port on a computer.
3. Launch *Device Configuration Utility* from *LoggerNet* or download from www.campbellsci.com/devconfig .
4. From the left side of the main screen, select the CSAT3B (note that there is no CSAT3BH selection, since the CSAT3BH functions like a CSAT3B when communicating with *Device Configuration Utility*) among the list of sensors. Select the appropriate communication port and baud rate (refer to the left side of [FIGURE 6-1](#) (p. 25)).
5. If this is the first time the computer has connected to a CSAT3BH, and depending on the computer settings, the USB driver may need to be manually installed. To do this, make sure the computer is connected to the internet and click **install the USB driver** link as shown in [FIGURE 6-1](#) (p. 25)).
6. Once the driver has been installed, if needed, click **Connect** at the bottom left of the window.

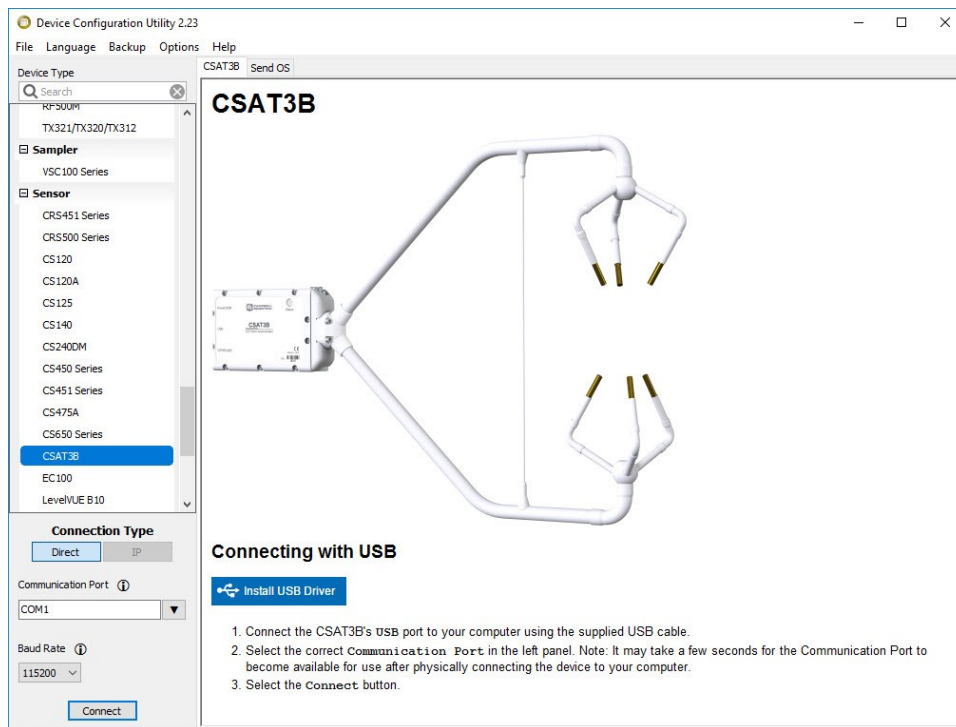


FIGURE 6-1. Connecting CSAT3BH using Device Configuration Utility

7. Once connected, the main screen will have a section with tabs to view the following four subscreens: **Real-Time Data**, **Communication Settings**, **Measurement Settings**, and **Instrument ID**. Table 6-1 (p. 26) describes each of the settings or status values in these subscreens. For each setting or status value, the factory default setting is noted by the footnote. Ensure that the appropriate settings are enabled for the communications protocol that will be used.

Table 6-1: CSAT3BH settings and status values in *Device Configuration Utility*

Subscreen	Setting or status value	Options	Description
Real-Time Data	Anemometer Data	-	Shows real-time measurements of u_x , u_y , u_z , sonic temperature (T_s), and the diagnostic word. If operating in Mode 0 (see Operating modes (p. 65)), values will flash each second. The Status light on the CSAT3BH will also flash red if in Mode 0 when no measurement triggers are being received from a data logger (for example, if a data logger is not connected to the CSAT3BH).
	Internal Temperature	-	Temperature inside CSAT3BH block
	Internal Relative Humidity	-	Relative humidity inside CSAT3BH block. Change desiccant if greater than 50% (see Desiccant (p. 85)).
	Inclinometer Pitch	-	Pitch angle of CSAT3BH head (see Mounting (p. 31))
	Inclinometer Roll	-	Roll angle of CSAT3BH head (see Mounting (p. 31))

Table 6-1: CSAT3BH settings and status values in *Device Configuration Utility*

Subscreen	Setting or status value	Options	Description
Communication Settings	SDM Address	1 through 14 3 ^{1/}	Unique address for SDM device
	CPI Address	1 through 120 30 ^{1/}	Unique address for CPI device
	Communication Port Protocol	Disable Both CPI Enabled ^{1/} RS-485 Enabled	Identifies whether the RS-485/CPI port will be disabled, enabled for CPI, or enabled for RS-485
	CPI Baud Rate	Auto ^{1/} 1000 kbps 500 kbps 250 kbps 125 kbps 50 kbps	Baud rate for CPI communications (in most circumstances this setting should remain set to Auto)
	RS-485 Baud Rate	1200 2400 4800 9600 19200 38400 57600 115200 ^{1/} 230400	Baud rate for RS-485 communications
	Unprompted Output Port	Disabled ^{1/} USB Port RS-485 Port	Identifies the port to output unprompted data
	Unprompted Output Rate	10 Hz ^{1/} 20 Hz 50 Hz 100 Hz	Identifies the rate at which to output unprompted data

Table 6-1: CSAT3BH settings and status values in *Device Configuration Utility*

Subscreen	Setting or status value	Options	Description
Measurement Settings	Operating Mode	<p>Mode 0: Data logger triggered No filter Data logger prompted output^{1/}</p> <p>Mode 1: Self triggered Filtered Data logger prompted output</p> <p>Mode 2: Self triggered No filter Unprompted output to computer</p> <p>Mode 3: Self triggered Filtered Unprompted output to computer</p>	Identifies the source of the measurement trigger, whether a low-pass filter will be applied, and the output mode (see Operating modes (p. 65) for more details)
	Filter Bandwidth	5 Hz 10 Hz 25 Hz	The cut-off frequency of the low-pass filter. Only applicable if in Operating Mode 1 or 3.
	Sonic Transducer Shadow Correction	Disabled Enabled	Applies an optional Kaimal correction for wind shadowing of the sonic transducers (see Sonic transducer shadow correction (p. 63))

Table 6-1: CSAT3BH settings and status values in *Device Configuration Utility*

Subscreen	Setting or status value	Options	Description
Instrument ID	Anemometer Serial Number	Serial Number ^{1/}	The serial number of the CSAT3BH
	User ID String	Blank ^{1/}	A unique identifier (in addition to the serial number) that the user may assign
	Factory ID String	Blank ^{1/}	A unique identifier (in addition to the serial number) that the factory may assign
	OS Version	-	The version number of the CSAT3BH operating system
	OS Date	-	The date the loaded operating system was built

^{1/} Denotes a factory default setting

NOTE:

Factory defaults for all settings may be restored by clicking the **Factory Defaults** button at the bottom of the screen in the *Device Configuration Utility*.

NOTE:

The SDM communications port is always enabled.

6.3.2 Set up the data logger and CSAT3H heater controller

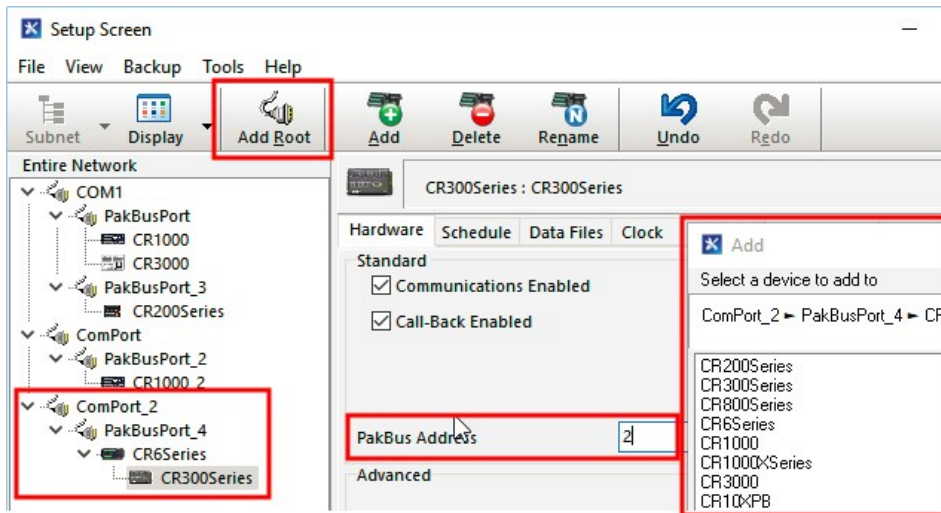
The data logger and CSAT3H heater controller box are configured in the setup screen of *LoggerNet*.

NOTE:

A CR6 or CR1000X data logger is recommended with the CSAT3BH. For information on configuring another data logger with the CSAT3BH, please contact Campbell Scientific.

1. From the *LoggerNet* toolbar, go to the **Standard** view of the setup screen by clicking **Setup**. The **Standard** view should be displayed. The blue button in the top right-hand corner of the screen allows the user to toggle between the **EZ** (Simplified) and **Standard** views.

- Click **Add Root** and select the means of communication (either **IPPort** or **ComPort**). **ComPort** is used in the illustrated example.
- From the **Add** window, select **PakBusPort**.
- From the **Add** window, select the data logger being used. A CR6Series is used in this example. The default **PakBus Address** for the CR6 is 1.
- From the **Add** window, add a CR300Series to the CR6Series, as it is the data logger with the CSAT3H heater controller. The **PakBus Address** of the CR300 inside the CSAT3H heater controller is set to 2, so the address must be changed from 1 to 2 in the **Hardware** tab.



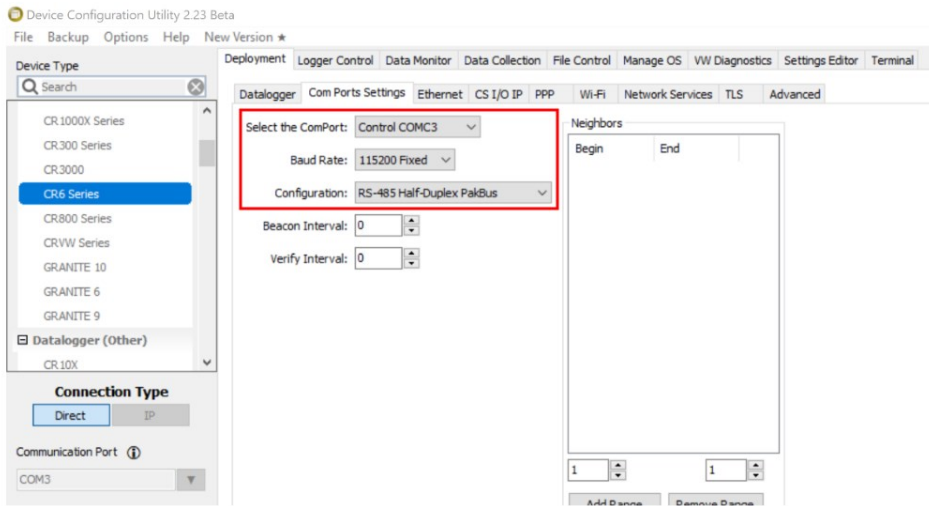
- Close the **Add** window.
- Make sure the PakBus addresses and ComPorts are correct. This allows for communication to and between the data logger and the heater controller box.

NOTE:

The PakBus addresses of the CSAT3H heater controller box (CR300) and the main data logger must be different, or communication interference will occur.

- Once everything is entered correctly, click **Apply**.
- If using IP, then follow the same steps and enter the IP address of the data logger.

10. Finally, connect your data logger with *Device Configuration Utility* and navigate to **Deployment > Com Ports Settings** and select **COM3** for **Select the ComPort**, **115200 Fixed** for **Baud Rate**, and **RS-485 Half-Duplex PakBus** for **Configuration**.



11. Select the **Advanced** tab and change **Is Router** to **True** for the CR6.
12. Click **Apply** to save settings.

6.4 Mounting

The CSAT3BH and CSAT3H controller box is supplied with mounting hardware to attach it to the end of a horizontal pipe with an outer diameter of 3.33 cm (1.31 in), such as the Campbell Scientific CM202, CM204, or CM206 crossarm (referred to generically as a CM20X crossarm). The following steps describe a general mounting procedure. The CSAT3H heater controller box must be mounted within 15 ft of the CSAT3BH. The temp/RH sensor used by the CSAT3H heater controller box has a 17 ft cable and should be mounted at the same level as the anemometer.

6.4.1 Mount the CSAT3BH

1. Secure the chosen crossarm to a tripod or other vertical structure using a CM210 crossarm-to-pole mounting kit as shown in [FIGURE 6-2](#) (p. 32).

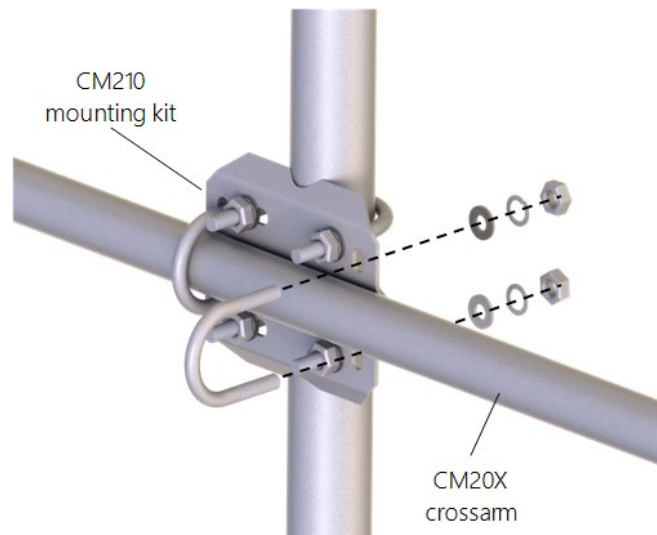


FIGURE 6-2. CM210 mounting kit with CM20X crossarm

2. Point the horizontal arm into the direction of the prevailing wind (for example, if the primary wind blows from the south, point the sensor to be facing south) and tighten the nuts and bolts of the mounting hardware.
3. Attach the CM250 leveling mount (included with the CSAT3BH) to the crossarm by tightening the set screws on the boom adapter with a 3/16-in hex socket head wrench. Refer to [FIGURE 6-3](#) (p. 33).
4. Attach the CSAT3BH to the leveling mount by inserting the bolt on the mount into the threaded hole on the bottom of the CSAT3BH block as shown in [FIGURE 6-3](#) (p. 33). The orientation of the CSAT3BH should be level and pointing in the direction of the prevailing wind.
5. Lightly tighten the bolt so that final leveling can be performed once all instrumentation is fully mounted to the structure.

CAUTION:

Do not carry the CSAT3BH by the arms or the strut between the arms. Always hold the CSAT3BH by the block, where the upper and lower arms connect.

CAUTION:

Over-tightening bolts will damage the screw threads in the CSAT3BH block.



FIGURE 6-3. CSAT3BH mounting

6.4.2 Mount CSAT3H

The CSAT3H heater controller box must be mounted within 15 ft of the CSAT3BH sensor due to cable length limitations.

1. Position the CSAT3H heater controller box such that it is within 15 ft of the sensor.
2. Mount the CSAT3H heater controller box to a tripod mast or other vertical structure using the U-bolts, flat washers, split washers, and nuts as shown in [FIGURE 6-4](#) (p. 33).

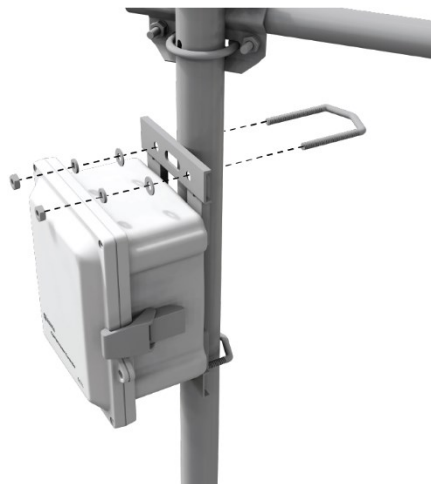


FIGURE 6-4. Mounting the CSAT3H to tripod mast

6.4.3 Mount the temperature/relative humidity probe

Mount the temperature/relative humidity (temp/RH) probe so that it is level with the sonic anemometer but doesn't impede the measurement path.

1. Use the U-bolt, 1/2-in screws, and washers included for mounting the dedicated temp/RH probe to the end of the crossarm as shown in [FIGURE 6-5](#) (p. 34).

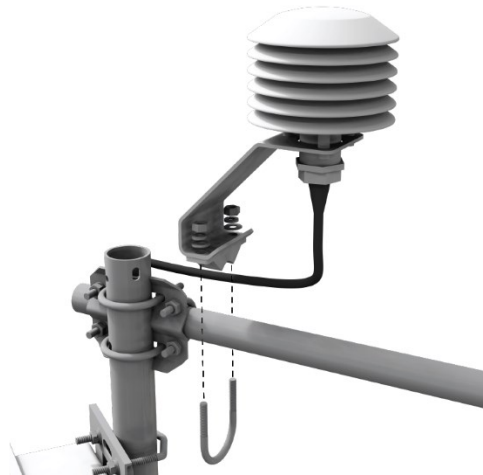


FIGURE 6-5. Mounting the temperature/relative humidity probe

6.5 Orientation

The three components of wind are defined by a right-handed orthogonal coordinate system. The CSAT3BH points into the negative x direction (see [FIGURE 6-8](#) (p. 37)). If the anemometer is pointing into the wind, it will report a positive u_x wind.

In general, the anemometer should be pointed into the prevailing wind to minimize interference from support structures such as the tower or tripod. Typically, the anemometer should be mounted level to the ground as described in [Leveling](#) (p. 36).

6.5.1 Sonic azimuth

The example programs report the wind direction in both the sonic coordinate system (a right-handed coordinate system; [FIGURE 6-6](#) (p. 35)) and in the compass coordinate system (a left-handed coordinate system; [FIGURE 6-7](#) (p. 36)). The sonic coordinate system is relative to the sonic itself and does not depend on the sonic orientation (azimuth of the negative x-axis). The compass coordinate system is fixed to Earth. For the program to compute the correct compass wind direction, the azimuth of the sonic negative x-axis must be entered into the program. The program default value for the variable `CSAT_AZIMUTH` is `0`. This assumes that the prevailing

wind is from the north (e.g., the sonic is mounted such that the negative x-axis points to the north). To change this to the appropriate azimuth, open the CRBasic program, navigate to **Const** CSAT_AZIMUTH, input the correct azimuth, and send this updated program to the data logger.

NOTE:

Remember to account for the magnetic declination at the site; see [CSAT3BH orientation](#) (p. 92) for details. If using an app on a cellular phone, magnetic declination is most likely already taken into consideration.

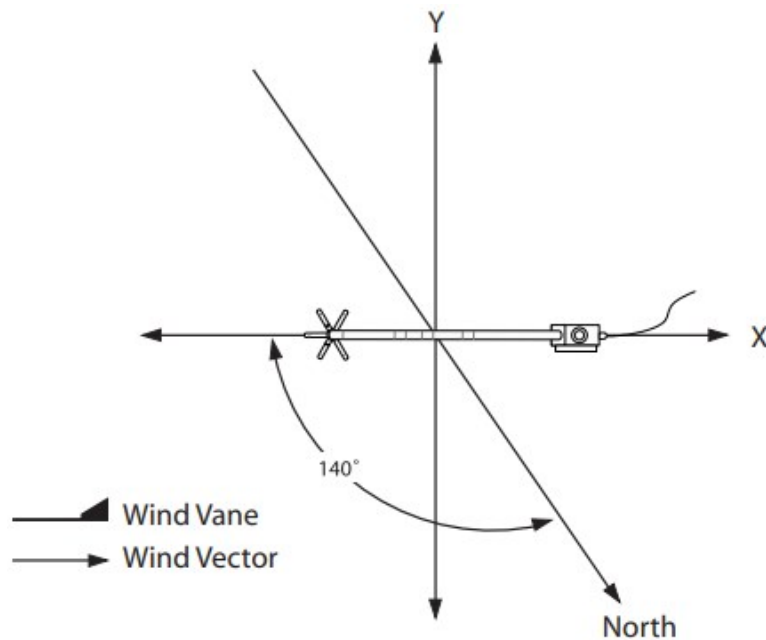


FIGURE 6-6. Right-hand coordinate system, horizontal wind vector angle is 0 degrees

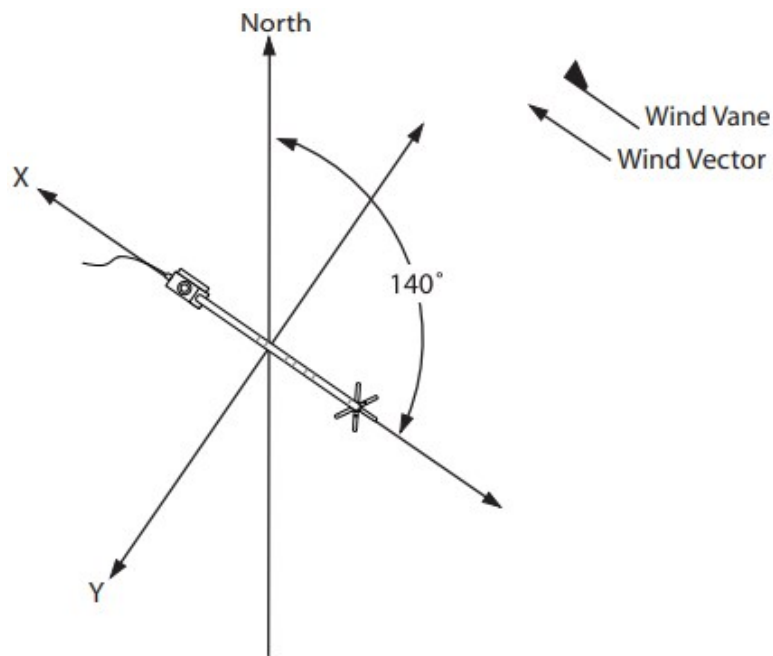


FIGURE 6-7. Compass coordinate system, compass wind direction is 140 degrees

6.6 Leveling

Leveling the CSAT3BH within a couple degrees is usually sufficient. The user commonly applies coordinate rotations to time series data to report the three-dimensional wind in a coordinate system where the x- and y-axes lie along the streamwise wind plane.

Adjust the anemometer head so that the bubble within the level on top of the CSAT3BH block is in the bullseye. Firmly grasp the sonic anemometer block, loosen the bolt underneath the block, and adjust the head accordingly. Finally, tighten the bolt with a 9/16-in wrench.

If an application requires greater accuracy in inclination of the CSAT3BH, or if an application requires a measurement that shows if, and when, the inclination of the CSAT3BH changes over time (for example, a sagging crossarm or tower tilt), an integrated inclinometer in the CSAT3BH can give pitch and roll measurements.

Pitch is the angle between the gravitationally horizontal plane and the CSAT3BH x-axis. A positive pitch angle corresponds to a clockwise rotation about the y-axis when looking down on the y-axis (see [FIGURE 6-8](#) (p. 37)). In other words, a positive pitch angle occurs when the transducer end of the CSAT3BH is pointed downwards, while a negative pitch angle occurs when CSAT3BH is pointed upwards.

Roll is the angle between the gravitationally horizontal plane and the CSAT3BH y-axis. A positive roll angle corresponds to a counter-clockwise rotation about the x-axis when looking down the x-axis (see [FIGURE 6-8](#) (p. 37)).

The inclinometer is sampled at a rate of 2 Hz and is not necessarily synchronized with the wind and sonic temperature data outputs. For applications that require correction for a moving measurement platform (on a buoy or ship, for example), a separate fast-response inclinometer, gyrometer, and accelerometer sensor should be used and sampled at the same rate as the CSAT3BH wind measurements.

The outputs of the CSAT3BH integrated inclinometer can be viewed by connecting the USB data cable to the CSAT3BH and a computer running Campbell Scientific *Device Configuration Utility*. It can also be output using the CRBasic instruction [CSAT3BMonitor\(\)](#). See [CSAT3BMonitor\(\)](#) (p. 75) for more information about setting this instruction.

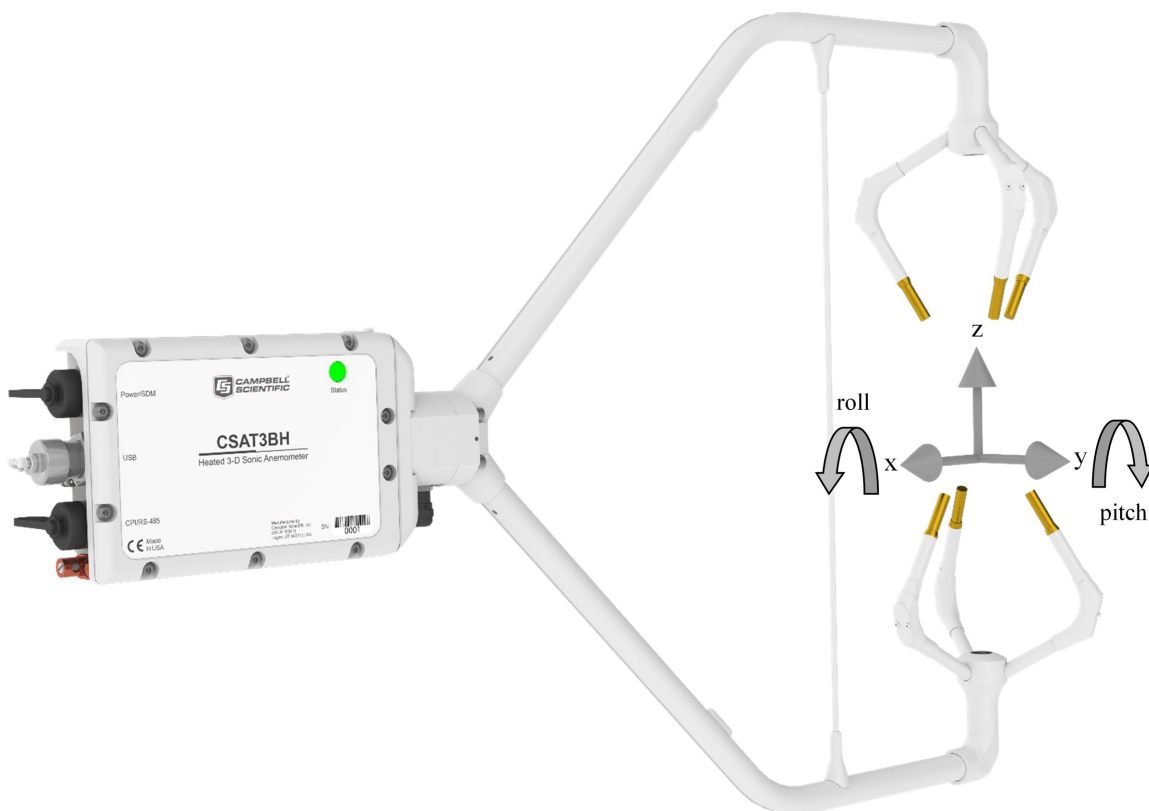


FIGURE 6-8. CSAT3BH shown with coordinate system, with arrows representing positive x-, y-, and z-axes; curved arrows indicate positive rotations of pitch and roll angles

6.7 Installing additional fast-response sensors

6.7.1 Fine-wire thermocouple

A fine-wire thermocouple (TC; model FW05 with a FWC-L cable, TC cover, and TC cover backplate) can be mounted to the side of the anemometer block to measure temperature fluctuations.

First, attach the TC cover backplate to the CSAT3BH with the screw that was included. Next, attach the socket connector from the FWC-L to the side of the anemometer with the short screw (#2-56 x 0.437 in) that was provided with the white thermocouple cover. Insert the pin connector of the FW05 into the socket connector of the FWC-L. Finally, attach the thermocouple cover to the anemometer block using the thumb screw so the FW05 and FWC-L connectors are both covered. See [FIGURE 6-9](#) (p. 38) for positioning and [FIGURE 6-10](#) (p. 39) with the FW05 fully installed.

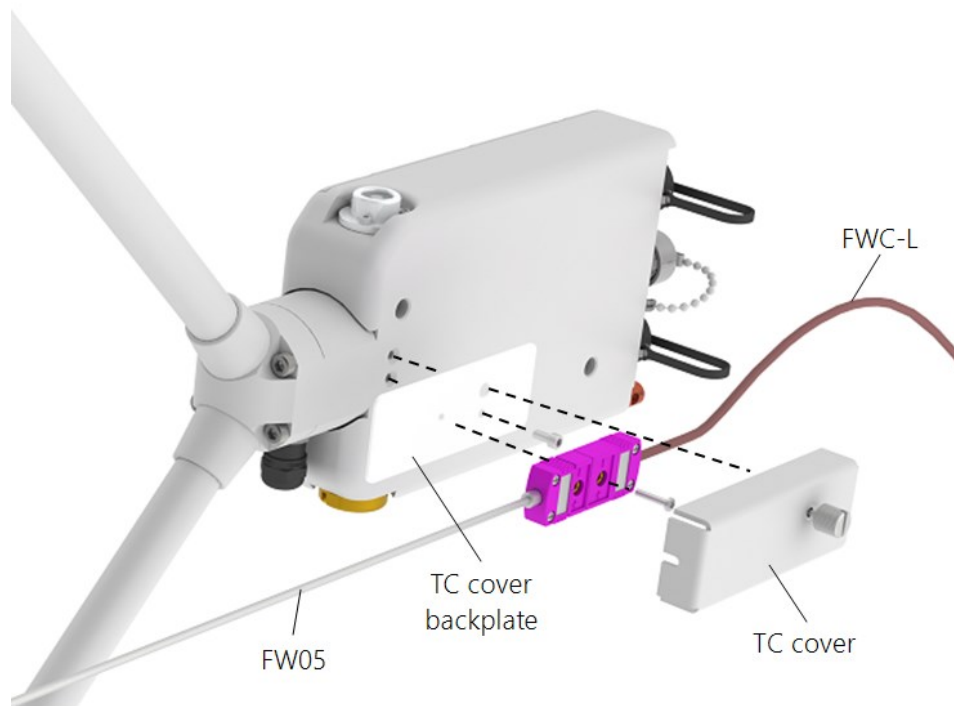


FIGURE 6-9. Exploded view of fine-wire thermocouple (TC) with CSAT3BH

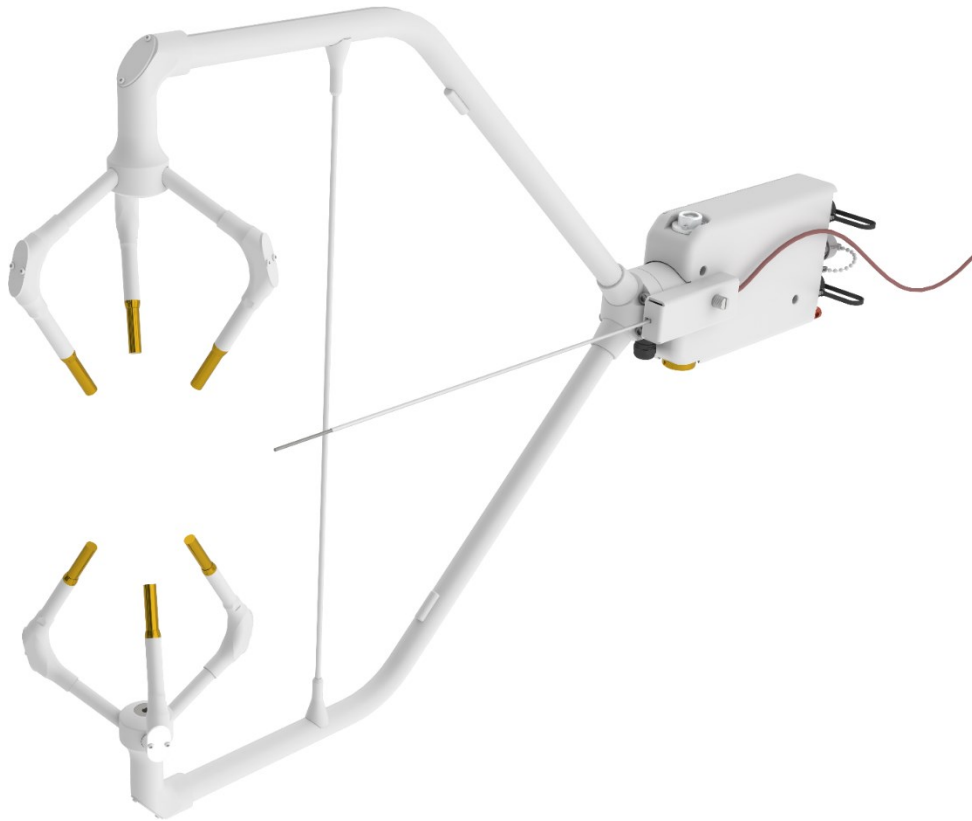


FIGURE 6-10. CSAT3BH with fine-wire thermocouple mounted

6.7.2 Other gas analyzers

If a fast-response gas analyzer is being used with the CSAT3BH, care should be taken to mount the analyzer (open-path) or the analyzer intake (closed-path) as close as possible to the sonic sampling volume in order to obtain good spatial and temporal synchronicity between vertical wind and gas concentration fluctuations while also retaining adequate spatial separation. This will avoid excessive wind distortion. In general, mount the analyzer or its intake downwind of the sonic sampling volume.

6.8 Wiring

6.8.1 Grounding to earth

The CSAT3BH, data logger enclosure, and CSAT3H heater controller box, must be earth grounded to the same grounding rod. They should be grounded from their grounding lugs (shown in [FIGURE 6-11](#) (p. 41) and [FIGURE 6-12](#) (p. 41), respectively) as described generally in the following steps.

CAUTION:

Grounding the CSAT3BH is critical. Proper grounding to earth will ensure maximum electrostatic discharge (ESD) and lightning protection and improve measurement accuracy. The data logger, CSAT3H heater controller box, and CSAT3BH electronics should all be grounded to the same grounding rod.

On the back of the CSAT3BH block is a copper grounding lug (refer to [FIGURE 6-11](#) (p. 41)). Use a standard flat-head screwdriver to pinch a wire (from 8 to 14 AWG) between the lug and the lug screw. Campbell Scientific offers a 10 AWG copper wire that is suitable for grounding sensors. Connect the other end of the wire to the tripod or tower, which should be grounded to earth with a grounding rod. A 5-ft copper-clad grounding rod ships with Campbell Scientific tripods, or it can be purchased separately.

The CSAT3BH has three watertight circular ports or connectors at the rear of the block. These are labeled **Power/SDM**, **USB**, and **CPI/RS-485** as shown in [FIGURE 6-11](#) (p. 41). Unless a port is in use and connected to a cable, they should be securely covered by one of the caps that are captive to the CSAT3BH.

1. Ground the CSAT3BH, data logger enclosure, and the CSAT3H controller box to the tower by attaching a user-supplied, heavy-gauge wire from the copper grounding lug on the back of the CSAT3BH block and the CSAT3H controller box (see [FIGURE 6-11](#) (p. 41) and [FIGURE 6-12](#) (p. 41)).
2. Earth (chassis) ground the other ends of the wires to the CSAT3BH mounting structure or to a grounding rod. Proper grounding lends stability and protection to a data acquisition system. It is the easiest and least expensive insurance against data loss—and often the most neglected. The following terminals are provided for CSAT3BH and CSAT3H controller box grounding.
 - a. \perp Signal ground reference for single-ended analog inputs, pulse inputs, excitation returns, and as a ground for sensor shield wires. Signal returns for pulse inputs should use \perp terminals located next to the pulse input terminal. Current loop sensors, however, should be grounded to power ground.
 - b. **G** Power ground return for 5V, SW12, and 12V terminals; current loop sensors; and C configured for control. Use of G grounds for these outputs minimizes potentially large current flow through the analog-voltage-measurement section of the wiring panel, which can cause single-ended voltage measurement errors.
 - c. \perp Earth ground lug connection point for a heavy gauge, earth ground wire. A good earth connection is necessary to secure the ground potential and shunt transients away from electronics. A minimum 14 AWG wire is recommended.



FIGURE 6-11. Grounding lug of CSAT3BH

NOTE:

If connecting multiple CSAT3BHs together either in a daisy chain series or star topology, each CSAT3BH must be separately grounded to either the mounting structure or a grounding rod.

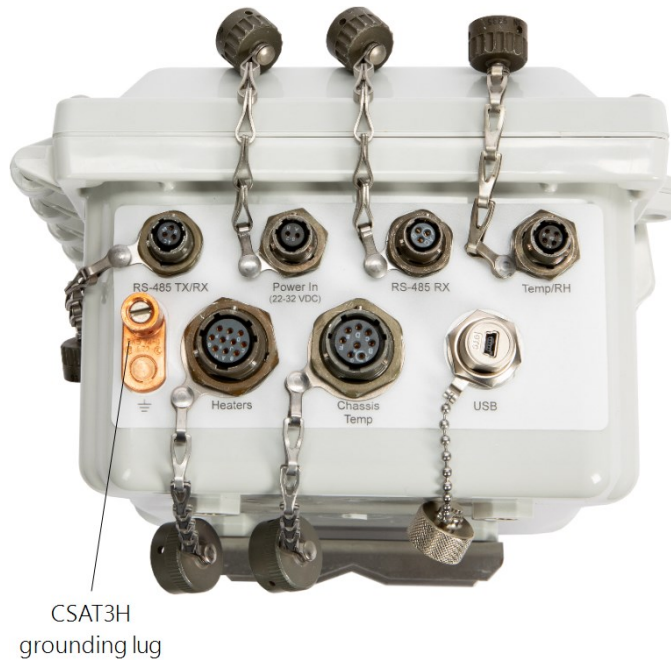


FIGURE 6-12. Grounding lug and connectors on bottom of CSAT3H heater controller box

Table 6-2: Cable wire assignments		
CSAT3BH cable type	Signal description	Pigtail color
CSAT3BCBL1	Power 9.5 to 32 VDC	Red
	Ground	Black
	SDM GND	Brown
	SDM C1	White
	SDM C2	Yellow
	SDM C3	Blue
	Shield	Clear
CSAT3BCBL2	Power 9.5 to 32 VDC	Red
	Ground	Black
CSAT3BCBL3	RxA	Brown
	RxB	Brown stripe
	TxA	Blue
	TxB	Blue stripe
	RGND	Green
CSAT3HCBL1	3-pin IP67	Brown, white, black
CSAT3HCBL2	3-pin IP67	Brown, white, black
CSAT3HCBL3	2-pin IP67	Red, black

The appropriate port and cable type to be used are determined by the chosen communication method. [Table 6-5](#) (p. 45) shows some of the criteria to use when determining the best communication method for a given application. Once a suitable method is determined, the appropriate combination of cables, connectors, and lengths should be used. (See [Power and communications cables](#) (p. 8) for information about ordering cables.)

6.8.2 Controller box connections

There are seven connectors on the CSAT3H heater controller box:

- RS-485 TX/RX
- Power In (22 to 32 VDC)
- RS-485 RX

- Temp/RH
- Heaters
- Chassis Temp
- USB

Using [FIGURE 6-12](#) (p. 41) as a guide, make the following connections to the CSAT3H heater controller box.

1. Connect the cable from the temp/RH probe to the heater controller connection labeled **Temp/RH**.
2. Connect the heater and chassis temp cables from the CSAT3BH to the **Heaters** and **Chassis Temp** connections on the heater controller.
3. Connect the cable from the external 22 to 32 VDC power supply to the **Power In** connection.
4. Connect the RS-485 cable to the **RS-485 TX/RX** connection. The other end of this cable connects to the data logger in the main enclosure.

6.8.3 CSAT3H heater controller connections

Data logger to CSAT3H heater controller communications

Using a CR6 or CR1000X as the data acquisition device requires communication to be established between the data logger and the CSAT3H heater controller. **RS-485** communication allows both of these devices to communicate to the other. The CSAT3HCBL1-L connects the **RS-485 TX/RX** port on the CSAT3H heater controller to the data logger **RS-485** terminal.

[Table 6-3](#) (p. 43) and [Table 6-4](#) (p. 44) shows the appropriate terminal connections for a CR6 and CR1000X, respectively. Since **RS-485** terminals on the data logger are limited, an MD485 will be required if no **RS-485** terminals are available in the user's application.

CR6 data logger terminal	Wire color
C3	Brown
C4	White
Ground	Black

CR1000X data logger terminal	Wire color
C5 or C7	Brown
C6 or C8	White
Ground	Black

Computer to CSAT3H heater controller communications

If using a computer or data acquisition system other than one from Campbell Scientific, then a 15-ft CSAT3HCBL2 cable will be used to communicate between the device acquiring data and the CSAT3H heater controller enclosure.

CSAT3H heater controller power input

Supply power to the CSAT3H heater controller by connecting the CSAT3HCBL3-L power cable from the 22 to 32 VDC power supply that is rated 150 W or more to the **Power In** connection. This power source will likely need to be in the form of AC mains power converted to a 22 to 32 VDC output.

CSAT3H heater controller Temp/RH, Chassis Temp, and Heater connections

Connect the temp/RH cable from the temp/RH probe to the CSAT3H heater controller box **Temp/RH** connector. Then connect the cable labeled **Chassis Temp** from the CSAT3BH anemometer to the connector on the CSAT3H heater controller box labeled **Chassis Temp**. Finally, connect the other cable coming out of the sonic anemometer labeled **Heaters** to the connector on the controller box labeled **Heaters**.

6.9 Communications

If the CSAT3BH is going to be operated using SDM or CPI communications where the data logger triggers the measurement and the data is unfiltered (see Mode 0 in [Operating modes](#) (p. 65)), then the CSAT3BH default settings are appropriate and do not require modification. If, however, the CSAT3BH will be operated in another mode that either requires data filters or uses USB or RS-485 communications, the settings must be modifying as described in [Settings](#) (p. 24).

NOTE:

Unlike previous CSAT3 models, the CSAT3BH does not include 7.6 m (25 ft) lengths of all cable types. Only the 5 m (16 ft) USB cable for initial configuration of the sensor is included. Other cables must be ordered separately.

Table 6-5: Summary of communications options for the CSAT3BH

	SDM	USB	CPI	RS-485
Data collection	Data loggers: <ul style="list-style-type: none"> • CR6 • CR800 • CR850 • CR1000 • CR1000X • CR3000^{1/} 	Computer	Data loggers: <ul style="list-style-type: none"> • CR6 • CR1000X 	Computer
Cable length	Medium	Short (< 5 m)	Longest	Long
Required cables	CSAT3BCBL1	CSAT3BCBL2 and USB cable (included)	CSAT3BCBL2 and CSAT3BCBL3	CSAT3BCBL2 and CSAT3BCBL3
Robustness	Better	Worse	Best	Better
Bandwidth	OK	Best	Best	OK
Synchronization with other sensors	Best	Worse	Best	Worse
Noisy environments	OK	OK	Best	Better

^{1/} Contact Campbell Scientific for instructions on how to configure a CR3000

NOTE:

CPI communication is preferred over SDM communication when using a CR6 or CR1000X data logger. See [Table 6-5](#) (p. 45) to examine the suitability of communications type based on various parameters for other combinations.

There are many possible configurations of multiple CSAT3BHs and other sensors on a single measurement station or system. Accordingly, power requirements and sensor cable lengths should be taken into account to appropriately power all sensors and avoid excess attenuation of signals. The following sections describe different types of communications and different configurations that may be helpful when designing the layout and configuration of a system. For additional help, contact Campbell Scientific.

NOTE:

For all communications types, if the total number of CSAT3BHs and other sensors powered by the data logger exceeds the limit of output current from the data logger, the power wires

must be connected to a separate 12 to 32 VDC nominal power supply. For long cables, a higher voltage power supply is recommended to compensate for voltage loss over long distances.

NOTE:

For CSAT3BH sensor networks with relatively long cables, the inductive impedance can be great enough to lead to short dips in voltage. If the voltage drops below 9.5 VDC at the input of any CSAT3BH sensor, that sensor will report a Low Voltage diagnostic bit (see [Table 7-6](#) (p. 76)), and the **Status** light will flash red. To resolve this issue, power the CSAT3BH network using a higher voltage (up to 32 VDC) or install a capacitor at one of the current loads. If needed, contact Campbell Scientific for assistance.

6.9.1 SDM communications

If data collection from the anemometer is to be accomplished using a data logger with SDM communications, connect a CSAT3BCBL1 to the **Power/SDM** port (as shown in [FIGURE 6-13](#) (p. 47)) by screwing the M16 connector into the port until tight. No other cables are required for SDM communications, as the CSAT3BCBL1 contains both power and SDM wiring.

If only one CSAT3BH is being measured, the opposite end of the cable will have wire pigtails to connect directly to the ports on a data logger. Refer to [Communications](#) (p. 44) for this wiring. [Table 6-6](#) (p. 48) and [Table 6-7](#) (p. 48) show the wiring diagrams for the CR6 and the CR1000X data loggers, respectively. Connect the white, yellow, and blue wires to the **U5**, **U6**, and **U7** terminals, respectively, on a data logger ([FIGURE 6-14](#) (p. 47)). On a data logger or another 9.5 to 32 VDC power supply, connect the red and black wires to the **12 V** and **G** terminals, respectively. See [FIGURE 6-14](#) (p. 47) and [Table 6-2](#) (p. 42) for wiring and wire color designations. For a CR1000X, see [Table 6-7](#) (p. 48).

For applications requiring very long cable lengths, a higher voltage power supply is recommended as voltage drop over long distances will occur and the CSAT3BH requires a minimum of 9.5 VDC.

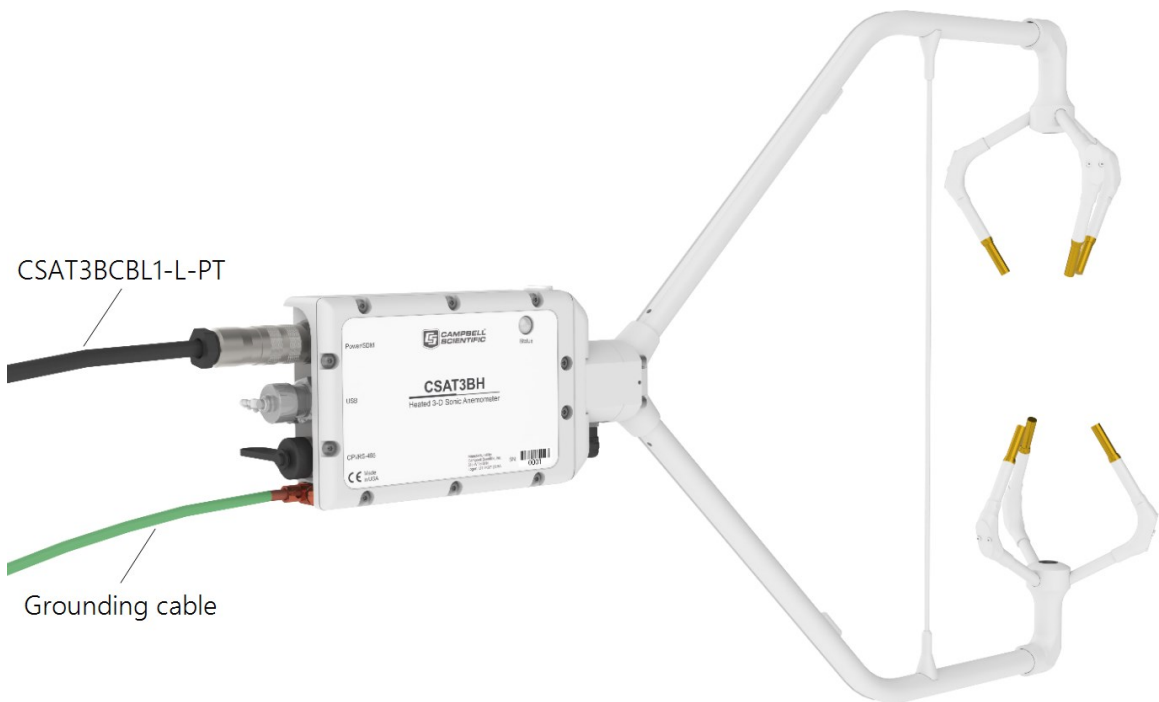


FIGURE 6-13. Power/SDM connections

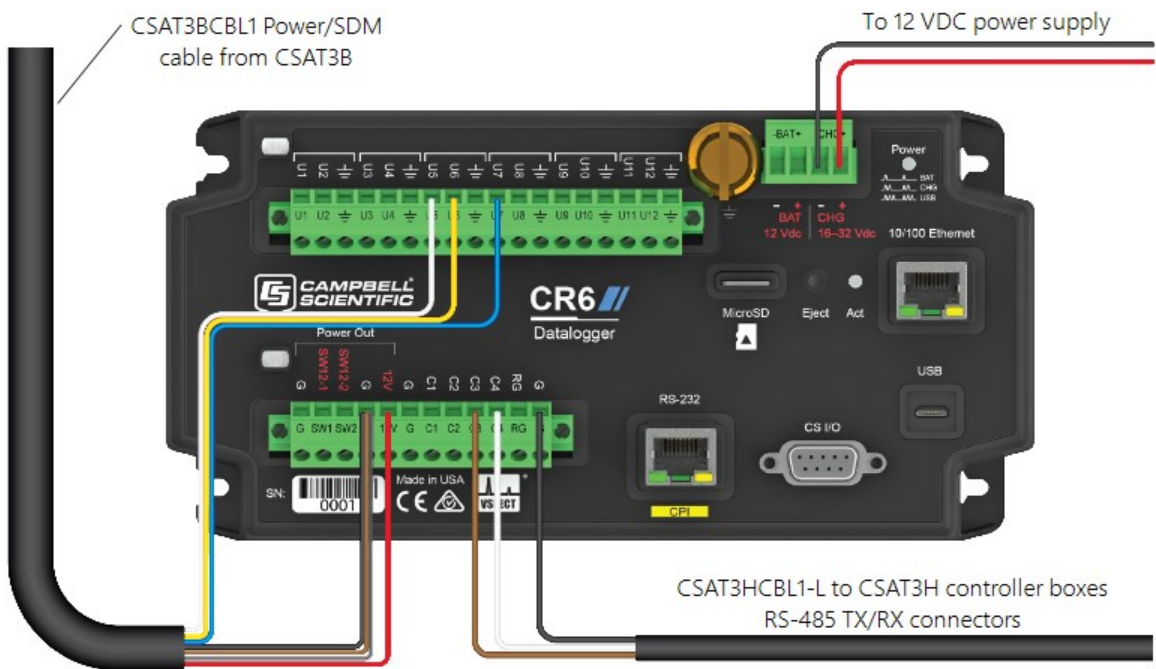


FIGURE 6-14. Wiring to power and SDM ports on CR6 data logger

CR6 data logger terminal	Wire color
12 V (or other 9.5 to 32 VDC source)	Red
Ground	Black
Ground	Brown
U5	White
U6	Yellow
U7	Blue
Ground	Clear

CR1000X data logger terminal	Wire color
12 V (or other 9.5 to 32 VDC source)	Red
Ground	Black
Ground	Brown
SDM C1	White
SDM C2	Yellow
SDM C3	Blue
Ground	Clear

1. Use *LoggerNet* or *PC400* to send a data logger program to the data logger. See [Data logger programming using SDM or CPI](#) (p. 73) for more information on data logger instructions and programming.
2. Verify that measurements are being made by ensuring the green **Status** light ([FIGURE 6-15](#) (p. 49)) on the CSAT3BH block is blinking, indicating that measurements are being made and recorded in the data logger without diagnostic error conditions.

NOTE:

In the default operating Mode 0, where the CSAT3BH measurement and output are triggered by a data logger (see [Operating modes](#) (p. 65) for more details), the CSAT3BH **Status** light will flash red until a data logger is connected to the CSAT3BH and its program is running and sending measurement triggers.



FIGURE 6-15. Lit status light on CSAT3BH block

6.10 Multiple CSAT3BH configurations

SDM daisy-chain topology

For an application that requires SDM communications from multiple CSAT3BHs in series, or with a daisy-chain topology, first connect to each CSAT3BH as described in [Settings](#) (p. 24) to ensure each sensor has been assigned a unique SDM address. Connect a CSAT3BCBL1 to the **Power/SDM** port of the CSAT3BH. The opposite end will have an M16 connector that is compatible with one of the split M16 connectors on the Power/SDM splitters. Next, screw the side of the splitter with only one M16 connector to the **Power/SDM** port of the second CSAT3BH. Connect another CSAT3BCBL1 to the splitter and down to the next CSAT3BH. Continue the daisy chain until the last CSAT3BH. The final CSAT3BCBL1 should have pigtail wire ends to connect to an external 12 VDC power supply. The CSAT3HCBL1-L cables from each CSAT3H heater controller box can either all go into the same ports, or all wires can re-route to a terminal connector with one set of wires routing to the data logger for a cleaner configuration. See [FIGURE 6-16](#) (p. 51).

SDM star topology

If several CSAT3BHs using SDM communications are being connected in parallel or with a star topology, connect a CSAT3BCBL1 cable to the **Power/SDM** port of each CSAT3BH, and connect the other wires on the pigtail end of the cables to a HUB-SDM8 bus (see [HUB-SDM8](#) (p. 15)).

Connect the wires so that all wires of a common color or signal are on the same rail. Then, use a CABLE5CBL with pigtail wires to connect the HUB-SDM to the **SDM** and **12 V** ports of a data logger. See [FIGURE 6-17](#) (p. 52).

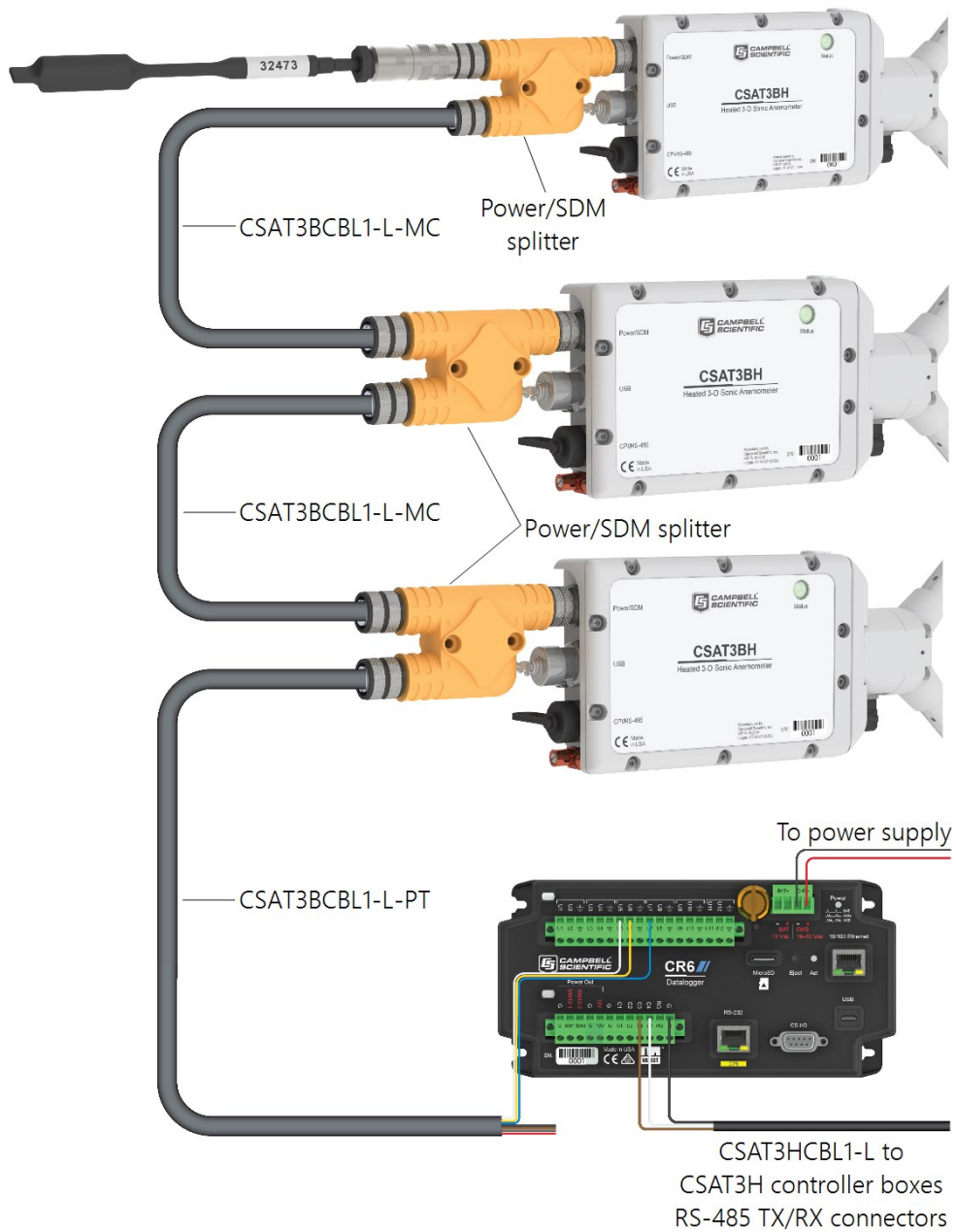


FIGURE 6-16. SDM daisy chain (CSAT3BH sensor arms and grounding cables not shown)

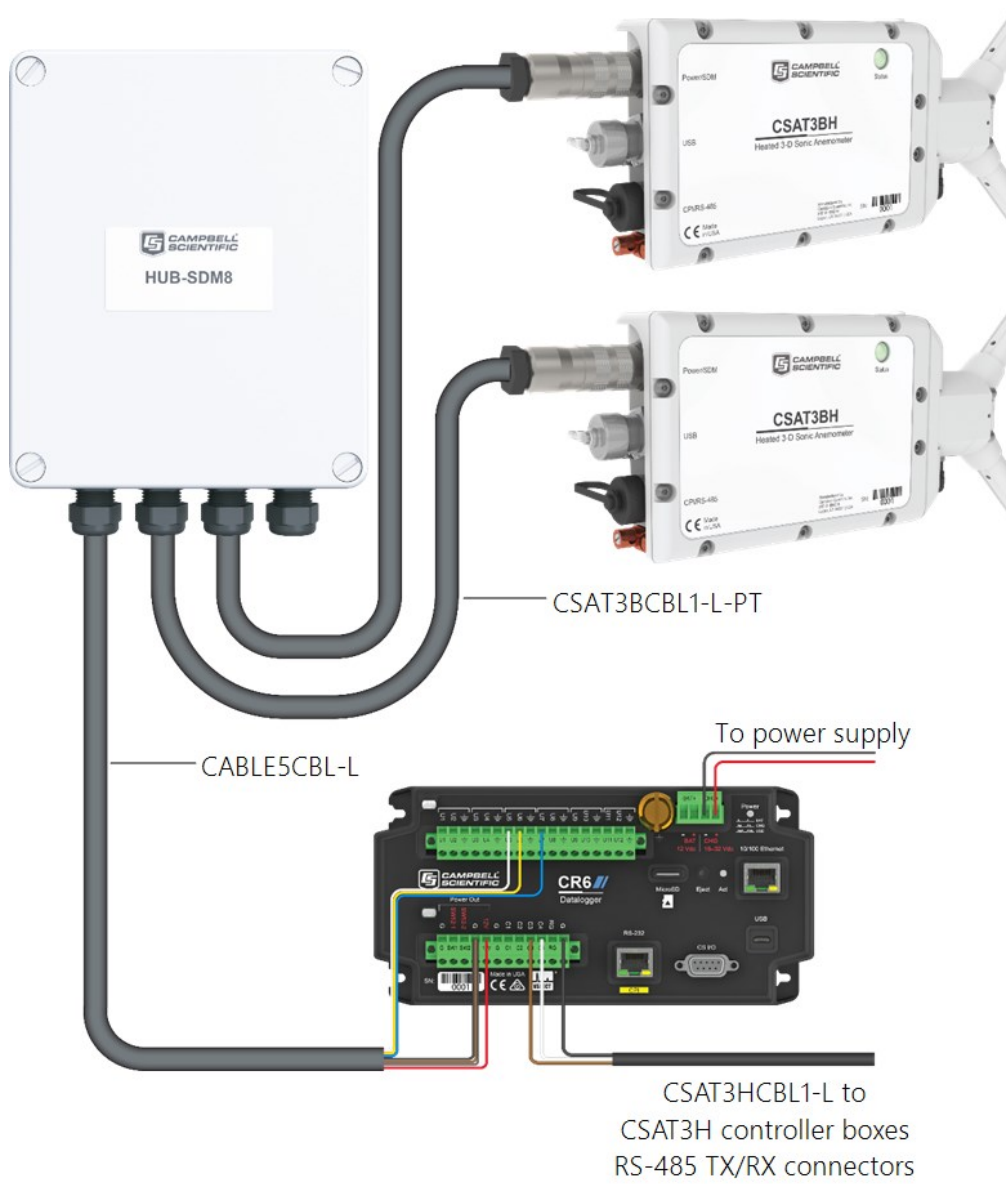


FIGURE 6-17. SDM star topology (CSAT3BH sensor arms and grounding cables not shown)

6.10.1 CPI communications

If data collection from the anemometer is to be done by a data logger using CPI communications, then connect a CSAT3BCBL2 to the **Power/SDM** port by screwing the M16 connector into the port until tight.

NOTE:

A CSAT3BCBL1 may also be used for power, but the SDM wires will not be used. The CSAT3BCBL1 also has lighter gauge power wires, which increases voltage loss over long cable lengths, so it should only be used for shorter cable lengths.

Next, connect a CSAT3BCBL3 to the **CPI/RS-485** port in the same manner. If only one CSAT3BH is being measured, the opposite end of the power cable should have pigtail wires that may be wired to the **12 V** and **G** terminals on a data logger or to a separate 12 to 32 VDC nominal power supply. The CPI cable should have the RJ45 connector plugged into the CPI port of the data logger. Finally, connect the CSAT3HCBL1-L RS-485 cable from the CSAT3H heater controller box to the designated C terminals on the data logger.

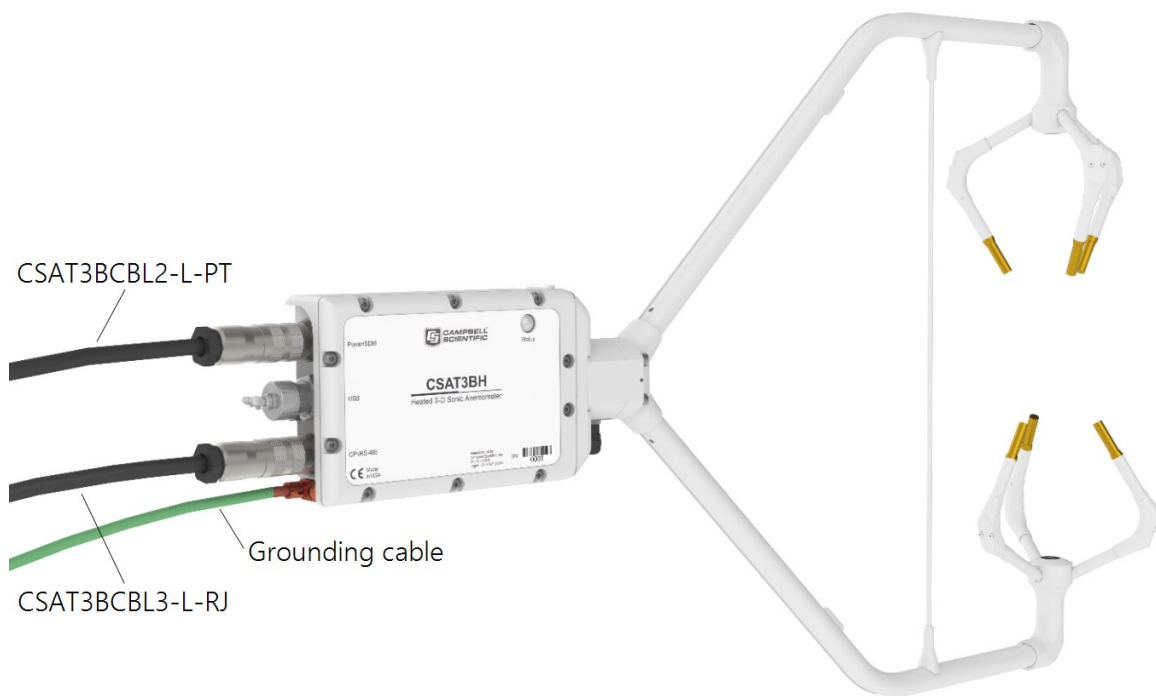


FIGURE 6-18. Power and CPI cable connections

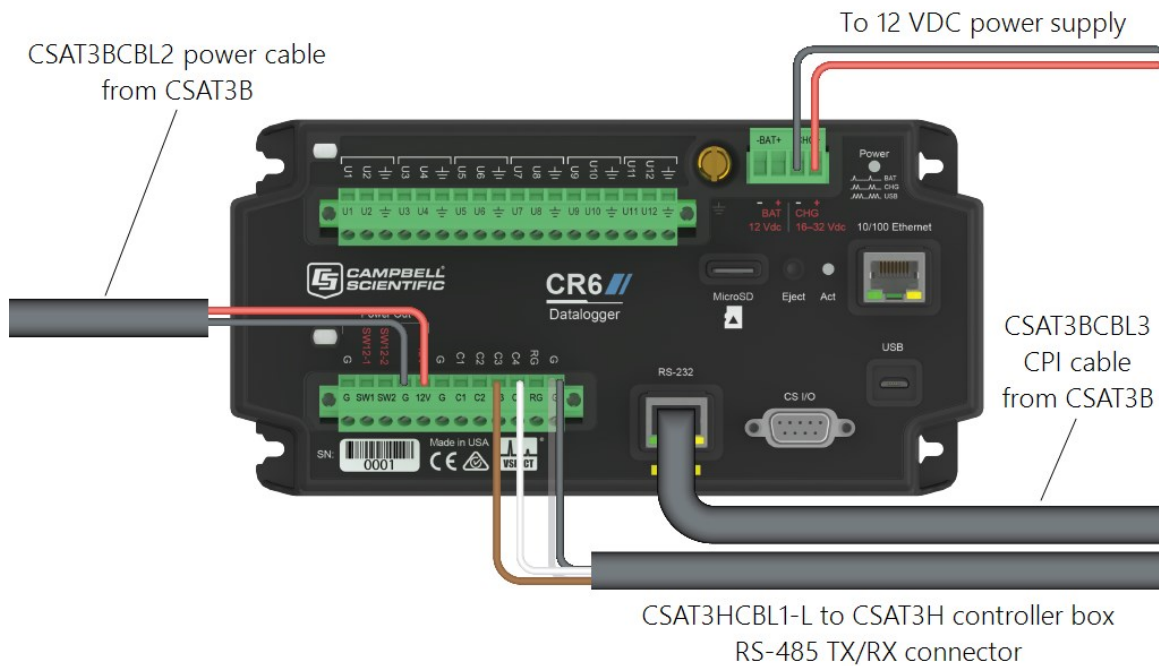


FIGURE 6-19. CPI connection to a CR6 data logger

CPI daisy-chain topology

For an application that requires CPI communication from multiple CSAT3Bs in series, or with a daisy-chain topology, first connect to each CSAT3B as described in [Settings](#) (p. 24) to give each sensor a unique CPI address. Then connect a CSAT3BCBL2 to the **Power/SDM** port and a CSAT3BCBL3 to the **CPI/RS-485** port on the terminal CSAT3B. The opposite end of the power cable should use an M16 connector to connect with one of the split M16 connectors on the power/SDM splitter. The opposite end of the CPI cable should use an M16 connector to connect with one of the split M16 connectors on the CPI/RS-485 splitter.

Screw the sides of the splitters with only one M16 connector to the **Power/SDM** and **CPI/RS-485** ports of the second CSAT3B. Connect another set of cables from these splitters down to the next CSAT3B. Continue the daisy chain until the last CSAT3B, where a final CSAT3BCBL2 should have pigtail wire ends to connect to the **12 V** and **G** terminals of a data logger or to a separate 12 to 32 VDC nominal power supply. The final CSAT3BCBL3 should have an RJ45 connector that plugs into the CPI port of the data logger. The CSAT3HCBL1-L cables from each CSAT3H heater controller box can either all go into the same ports or be re-routed to a terminal connector with one set of wires routed to the data logger for a cleaner configuration. Refer to [FIGURE 6-20](#) (p. 56) for the described connections.

CPI star topology

If several CSAT3Bs using CPI communications are being connected in parallel or with a star topology, connect a CSAT3BCBL2 cable to each **Power/SDM** port of each CSAT3B, and connect the other wires to the **12 V** and **G** terminals of a data logger or to a separate 12 to 32 VDC nominal power supply. (For convenience, it is possible to use a wiring bus, such as the HUB-SDM8, to bring several power wires together and then extend a single cable, such as the CABLEPCBL-L, from the bus to the power supply.)

Connect a CSAT3BCBL3 to each **CPI/RS-485** port of each CSAT3B, and connect the opposite end, which should have RJ45 connectors, to a HUB-CPI. Then, use a CAT5e or CAT6 Ethernet cable to connect the HUB-CPI to the CPI port of a data logger. The CSAT3HCBL1-L cables from each CSAT3H heater controller box can either all go into the same ports, or all wires can re-route to a terminal connector with one set of wires routed to the data logger for a cleaner configuration. Refer to [FIGURE 6-21](#) (p. 57) for these connections.

NOTE:

The sockets or ports on the HUB-CPI are all the same. Any socket may be used to connect to the data logger or to other CSAT3Bs.

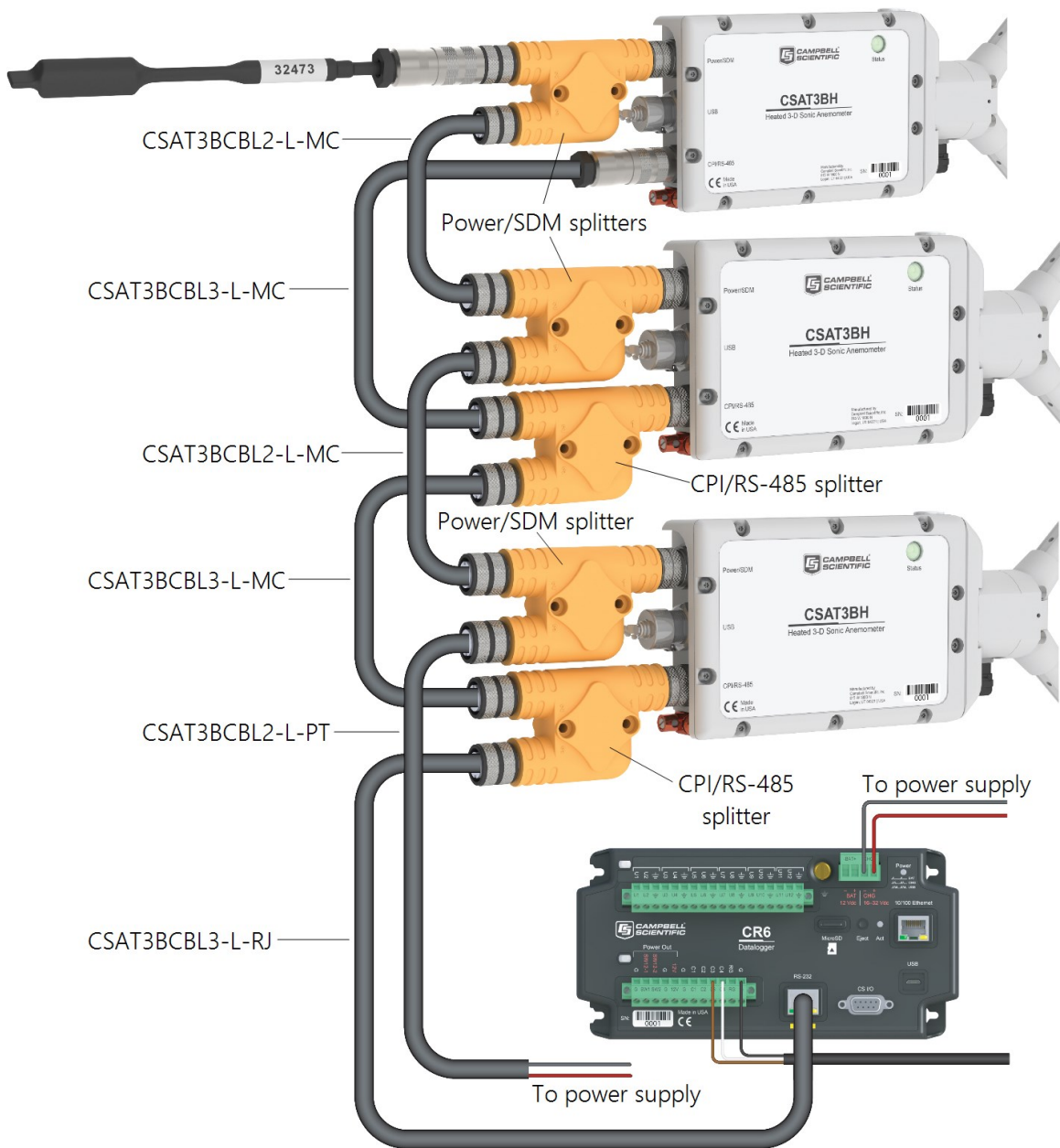


FIGURE 6-20. CPI daisy chain (CSAT3BH sensor arms and grounding cables not shown)

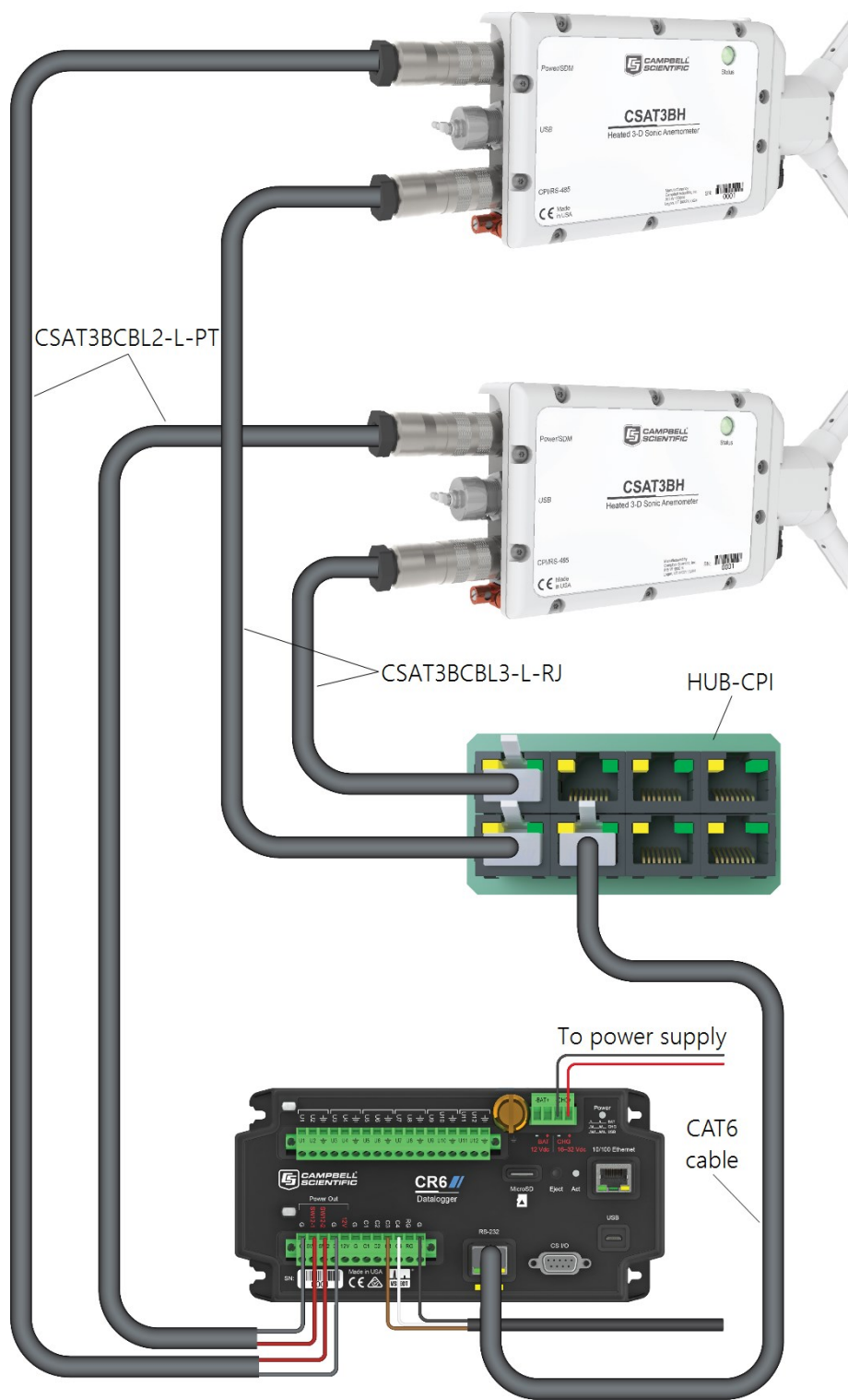


FIGURE 6-21. CPI star topology (CSAT3BH sensor arms and grounding cables not shown)

6.10.2 RS-485 communications

If data collection from the anemometer is to be accomplished by a computer using RS-485, first connect the CSAT3BH as described in [Settings](#) (p. 24) to confirm the following four settings:

Operating Mode (choose one of the following):

- Mode 2: Self-triggered | No filter | Unprompted output to computer
- Mode 3: Self-triggered | Filtered | Unprompted output to computer (if Mode 3, select filter bandwidth)

CPI/RS-485 Communication Port Protocol: RS-485 Enabled

RS-485 Baud Rate: 115200 or other appropriate value

Unprompted Output Port: RS-485 Port

- Unprompted Output Rate: 10, 20, 50, or 100 Hz

NOTE:

In *Device Configuration Utility*, the settings for **Unprompted Output Port** and **Unprompted Output Rate** will be grayed-out until the operating mode has been set to Mode 2 or Mode 3.

To complete installation, connect a CSAT3BCBL2 to the **Power/SDM** port by screwing the M16 connector into the port until tight.

NOTE:

A CSAT3BCBL1 may also be used for power, but the SDM wires will not be used. The CSAT3BCSBL1 also has lighter gauge power wires, which increases voltage loss over long cable lengths, so it should only be used for shorter cable lengths.

Next, connect a CSAT3BCBL3 cable to the **CPI/RS-485** port in the same manner. If only one CSAT3BH is being measured, the opposite end of the power cable should have pigtail wires, which may be connected to a 9.5 to 32 VDC power supply, and the RS-485 cable should have pigtail wires for wiring to a connector on a computer (see [FIGURE 6-22](#) (p. 59)). Refer to [Table 6-5](#) (p. 45) for a summary of the receive-and-transmit wiring.

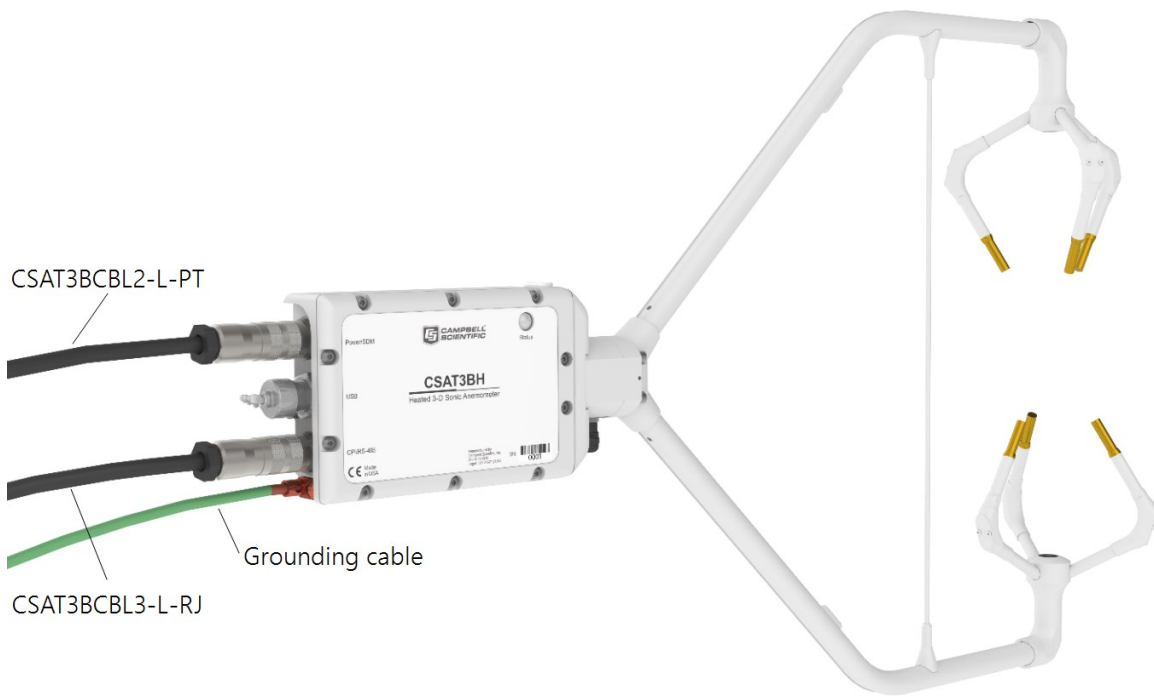


FIGURE 6-22. RS-485 cable connections

6.10.3 USB

If data collection from the anemometer is to be done by a computer using USB communications, first connect to the CSAT3BH as described in [Settings](#) (p. 24) to confirm the following three settings:

Operating Mode (choose one of the following):

- Mode 2: Self-triggered | No filter | Unprompted output to computer
- Mode 3: Self-triggered | Filtered | Unprompted output to computer (if Mode 3, select filter bandwidth)

Unprompted Output Port: USB Port

Unprompted Output Rate: 10, 20, 50, or 100 Hz

NOTE:

In *Device Configuration Utility*, the settings for **Unprompted Output Port** and **Unprompted Output Rate** will be grayed-out until the operating mode has been set to Mode 2 or Mode 3.

To complete installation, connect a CSAT3BCBL2 to the **Power/SDM** port by screwing the M16 connector into the port until tight.

NOTE:

A CSAT3BCBL1 may also be used for power, but the SDM wires will not be used. The CSAT3BCBL1 also has lighter gauge power wires, which increases voltage loss over long cable lengths, so it should only be used for shorter cable lengths.

Connect the 5 m (16 ft) USB cable included with the CSAT3BH to the USB port in the same way. If only one CSAT3BH is being measured, the opposite end of the power cable should have pigtail wires, which may be connected to a 9.5 to 32 VDC power supply, and the USB cable should be connected to a USB port on a computer.

For a watertight connection to the USB port, use the included USB cable. For a temporary, non-watertight connection to the USB port, any USB type A pin to type mini-B pin cable can be used.

WARNING:

Unused ports on the CSAT3BH block should always be covered securely by the caps to avoid water damage to the electronics.

If a fine-wire thermocouple such as a model FW05 with FWC-L is being used, the wiring designations in [Table 6-8](#) (p. 60) should be followed to connect the thermocouple to a differential voltage terminal on a data logger.

Description	Color
Signal high	Purple
Signal low	Red

6.11 Confirm CSAT3BH factory settings

The CSAT3BH is shipped from the factory with the default settings that are shown in [Table 6-9](#) (p. 61). These settings can be changed with a computer running Campbell Scientific *Device Configuration Utility*, version 2.10 or newer, and the USB cable that ships with the CSAT3BH. *Device Configuration Utility* is available from the Campbell Scientific website at www.campbellsci.com/downloads and is included with *LoggerNet* and *PC400* software packages.

	Setting	Default
Communication settings	SDM address	3
	CPI address	30
	CPI/RS-485 Communication Port Protocol	CPI Enabled
	CPI Baud Rate	Auto
	RS-485 Baud Rate	115200
	Unprompted Output Port	Disabled
	Unprompted Output Rate	10 Hz
Measurement setting	Operating Mode	Mode 0: Data Logger Trigger No Filter Data Logger-Prompted Output

7. Operation

7.1 Theory of operation for wind and sonic temperature measurements

The CSAT3BH uses three pairs of non-orthogonally oriented transducers that transmit and receive ultrasonic signals. The time of flight of a sonic signal between a pair of transducers is directly related to the wind vector component that is parallel to the sonic axis. The CSAT3BH is able to calculate the wind vector components along each sonic axis using the time difference between an outgoing and return sonic signal, along with the distance between sonic transducers. Trigonometric relationships are used to calculate the wind speed in an orthogonal x-y-z coordinate system.

The time of flight measurement is also related to the speed of sound in air, which is a function of the air density (temperature and humidity). Through these relationships, the CSAT3BH is able to output a measurement of sonic air temperature from which actual air temperature may be calculated if humidity is known.

For more complete details on the theory of operation of the CSAT3BH, refer to [CSAT3BH measurement theory](#) (p. 95).

7.1.1 Algorithm Version 5

Since the release of the original CSAT3 in 1996, various improvements have been made to the algorithms used for signal processing and measurement output. Each time a significant change has been made to these algorithms, a new version number has been issued. The CSAT3BH uses algorithm Version 5. Version 5 maintains many of the advantages of signal recognition and diagnostic sensitivity that were made possible by Version 3, while also adding the advantages of performance during precipitation events made possible by Version 4. It also resolves Version 4 issues of speed-of-sound measurement errors in very high wind conditions as reported by Burns et al. (2012; see [References](#) (p. 91)).

7.1.2 Effects of crosswind on the speed of sound

The speed of sound is found by combining the out and back time-of-flight measurements (see Equation B-5 in [CSAT3BH measurement theory](#) (p. 95)). While the parallel component of the wind along the sonic axis does not affect the measured speed of sound, the perpendicular component does. An online calculator can account for the effects of the perpendicular component of wind using the measured components of wind and simple trigonometry, or manually by using the methods described by Schotanus, Nieuwstadt, and de Bruin (1983) and Liu, Peter, and Foken (2001; see [References](#) (p. 91)). The CSAT3BH corrects for the effects of crosswind on the speed of sound.

The equations derived by Schotanus, Nieuwstadt, and de Bruin (1983) apply to sonic anemometers that make speed of sound measurements from a single pair of transducers. Liu, Peter, and Foken (2001) extend these equations to sonic anemometers that measure the speed of sound on all three axes and then average the results to a single speed of sound, as with the CSAT3BH. Liu, Peter, and Foken (2001) assume that the geometry of each individual three-dimensional anemometer is ideal when given factors are derived, as found in Table 1 of their publication.

NOTE:

Liu, Peter, and Foken (2001) recommend that CSAT3BH sonic temperature variances and sonic sensible heat flux are corrected for the effects of crosswind. The CSAT3BH, however, performs an online correction. Additional correction of CSAT3BH data for crosswind effects will cause errors in the measured fluxes.

7.1.3 Sonic transducer shadow correction

The CSAT3, CSAT3A, CSAT3B, and CSAT3BH suffer minimal wind distortion compared to many other sonic anemometer designs because of a very low ratio of transducer diameter to sonic path length, and because the non-orthogonal geometry keeps the sonic paths at angles closer to perpendicular with respect to a mean horizontal wind flow. However, there are cases, such as when oncoming wind has high angles of attack (for example, low frequency eddies on a tall tower), that will lead to more shadowing. Accordingly, an **optional** wind shadow correction specific to the CSAT3-series transducer diameter and sonic path length has been implemented in the CSAT3BH OS versions 1.11 and newer.

This shadow correction, known as the Kaimal correction (Kaimal 1979; Horst, Semmer, and Maclean 2015), is applied according to:

$$U_{i_{measured}} = U_i (0.84 + 0.16 \sin(\theta))$$

Where:

U_i = the magnitude of the wind vector parallel to the sonic path without shadowing errors

i = a placeholder index for a , b , or c , representing the three sonic paths

θ_i = the angle between the three-dimensional wind vector and the wind vector component along the a -, b -, or c -sonic path (see [FIGURE 7-1](#) (p. 64))

The CSAT3BH embedded code improves the estimates of θ — and therefore the accuracy of the correction — by iteratively applying the preceding correction three times for each measurement of each sonic path. Since debate continues on the appropriateness of this and other shadow corrections in turbulent versus laminar flows, the default of this setting is **Disabled**.

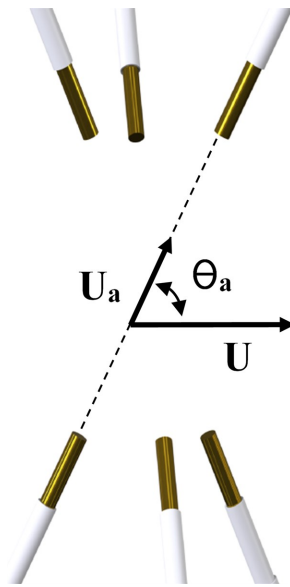


FIGURE 7-1. Angle θ_a is defined as the angle between the vector of oncoming wind (U) and the wind component along the a -sonic path, (U_a).

7.2 Theory of heater controller operation

The CSAT3BH and CSAT3H heater controller box use a heater algorithm to variably control the heaters on the sonic head. There are two zones of heating. Zone 1 is the arms and strut, while zone 2 is located on each transducer finger.

The controller is programmed to operate in two modes. The first mode controls the heater voltage to maintain a temperature on the transducers above dew point when the ambient temperature is less than 2 °C, as determined by the temperature/relative humidity probe.

The second mode controls the heater voltage to clear a blockage of ice or snow, based on sonic diagnostic flags. If, within 60 seconds, the average number of diagnostic flags coming from the CSAT3BH is greater than 25 percent, the controller will go into the second mode. In the second mode, the heater voltage will increase every 15 minutes until the blockage is clear. Once the blockage is clear, indicated by the average number of diagnostic flags dropping below 25 percent, the controller will go back into the first mode and control the heaters to maintain the temperature setpoints in zone 1 and zone 2 above dew point.

The heaters will not allow the temperature on the transducers or arms to go above 38 °C. Additionally, if any of the temperature readings on the sonic head are above 45 °C, the heaters will shut off. Finally, in the situation of a heater failure, indicated by a delta temperature between the maximum and minimum temperature recorded on the arms and transducers greater than 15 °C, the heaters will shut off and the controller will stop running.

7.3 Operating modes

The CSAT3BH has different operating modes that are selected based on the desired measurement trigger source, presence of a data filter, and type of data output. Specifically, the following four modes are available:

- Mode 0: Data logger triggered | No filter | Data logger prompted output
- Mode 1: Self triggered | Filtered | Data logger prompted output
- Mode 2: Self triggered | No filter | Unprompted output to computer
- Mode 3: Self triggered | Filtered | Unprompted output to computer

The mode is selected using the *Device Configuration Utility* under the **Measurement Settings** tab (see [Settings](#) (p. 24) for details on viewing and selecting settings). [Table 7-1](#) (p. 66) gives a summary of the CSAT3BH operating modes. The following sections give more information on the measurement trigger, data filters, and data output as a guide to selecting the appropriate mode. Mode 0 is the default operating mode for the CSAT3BH and is recommended when fluxes are the primary interest.

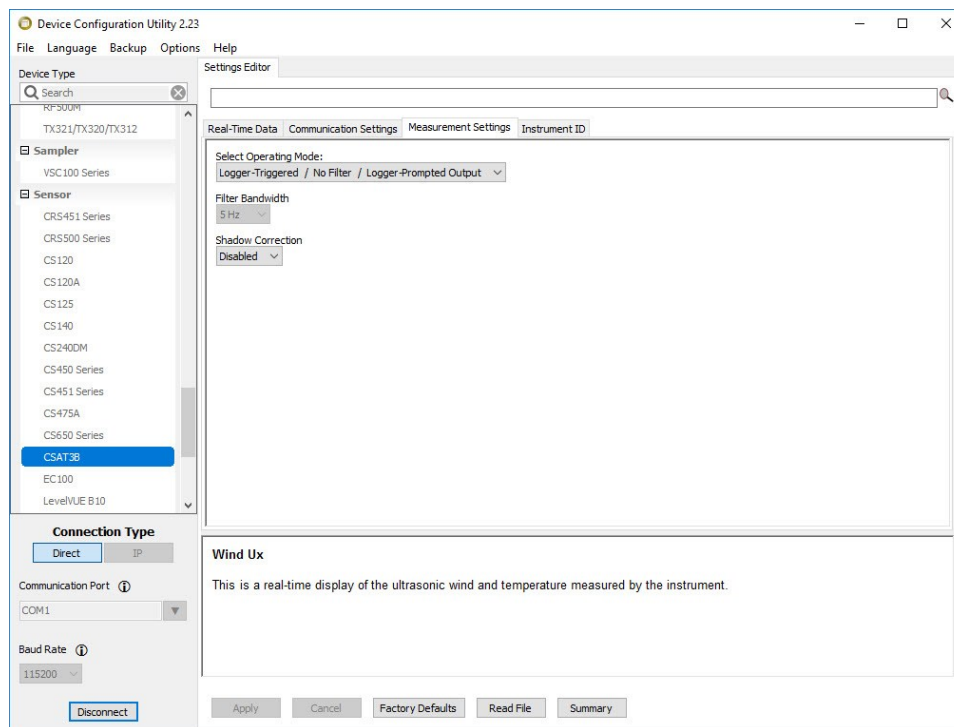


FIGURE 7-2. Measurement settings in *Device Configuration Utility*

Table 7-1: Overview of CSAT3BH operating modes

Mode	Measurement Trigger		Filters		Output Prompt	
	Source	Rate	Enabled	Bandwidth (Hz)	Source	Rate
0	Data logger	1 to 100 Hz ^{1/}	No	-	Data logger	1 to 100 Hz ^{1/}
1	CSAT3BH	100 Hz	Yes	5, 10, 25	Data logger	1 to 100 Hz ^{1/}
2	CSAT3BH	100 Hz	No	-	CSAT3BH	10, 20, 50, 100 Hz
3	CSAT3BH	100 Hz	Yes	5, 10, 25	CSAT3BH	10, 20, 50, 100 Hz

^{1/} The exact rate is determined by the scan interval set in the CRBasic program of the data logger.

NOTE:

Data logger prompted output using Mode 0 requires use of SDM or CPI communications. Data logger prompted output using Mode 1 requires CPI communications (SDM not compatible with bandwidth filters). The options for unprompted output to a computer require use of RS-485 or USB communications.

7.3.1 Measurement trigger

A measurement trigger is the actual command to initiate a sonic measurement and can be driven by either a data logger or the CSAT3BH internal timer. If the trigger is given by a data logger as in Mode 0, then no data filtering is done (bandwidth is wide open) since each trigger will initiate a single new measurement (single-measurement regime). The data logger can trigger measurements at rates from 1 to 100 Hz. If the trigger is given by the internal CSAT3BH timer as in Modes 1 through 3, the measurements will be self-triggered at a rate of 100 Hz. This results in an oversampled measurement regime where the 100 Hz samples may be optionally processed through a filter before being down sampled or decimated and output.

NOTE:

If a data logger fails to provide a trigger and the CSAT3BH has not been configured for unprompted output, the CSAT3BH will enter into a lost-trigger state where it will output measurements at 1 Hz based on its internal timer. If the CSAT3BH is in a lost-trigger state while connected with *Device Configuration Utility*, real-time anemometer data will flash on the screen at one-second intervals, and the LED **Status** light on the CSAT3BH head will flash red. This is an indication that the settings should be checked. It does not indicate a problem with the CSAT3BH hardware. Once a trigger is received by the CSAT3BH, or once unprompted output is enabled, normal operation will ensue.

7.3.2 Data filter

The optional data filter (Modes 1 and 3) takes the 100 Hz sample points that were self-triggered by the CSAT3BH and runs them through a low-pass (high-cut) filter, resulting in a new filtered output at the same 100 Hz rate. The degree to which the data is filtered is determined by the user-selected filter bandwidth. This is selected from the *Device Configuration Utility* in the **Measurement Settings** tab.

The bandwidth is the frequency at which a signal is filtered to $(1 - 1/e)$ of its original power. In cases where unaliased spectra from the CSAT3BH are to be analyzed, the user should choose a filter bandwidth that is at the Nyquist frequency, which is half the data output rate from the CSAT3BH to the data logger or computer. This will eliminate aliasing or the mismatch of signals to frequencies. The bandwidths that are available for selection are 5, 10, 20, and 25 Hz. Each mode and bandwidth results in a different time delay between measurement and output. [Table 7-2](#) (p. 67) summarizes these time delays which will need to be accounted for when aligning CSAT3BH data with data from other fast-response sensors. Data alignment can be done automatically with a data logger or during post-processing on a computer. [Table 7-4](#) (p. 73) also shows the closest integer sample delays for various output rates.

If the primary interest of a study is fluxes rather than spectral analysis, there is no need to select a filter. With unfiltered data, the anemometer high-frequency response is limited only by the geometry of the anemometer head. This minimizes the possibility of underestimating high-frequency signal variations and covariations. This approach, however, aliases high-frequency information to lower frequencies. This aliasing is apparent in spectra from an upwards tail, when compared to the $-5/3$ power relationship (Kaimal and Finnigan 1994), at frequencies approaching the Nyquist frequency of one-half the sample rate. This aliasing does not compromise the variances and covariances (and therefore fluxes) computed from aliased data. The variance and covariance calculations are not frequency dependent, they simply measure total variation from one signal or total covariation from two signals, respectively. Given this, under circumstances where measuring fluxes are the primary interest, it is recommended to operate without a filter and, if possible, have the data logger provide the trigger.

Mode	Delay between measurement and output		
0	1 Data logger scan interval		
2	10 ms		
1 and 3	Bandwidth	5 Hz	795 ms
		10 Hz	395 ms
		25 Hz	155 ms

NOTE:

Modes 1 and 3 and the associated bandwidth filters were fully supported starting with CSAT3BH OS versions 1.09 and newer.

7.3.3 CSAT3BH sonic data output

After a measurement is triggered and optionally run through a filter, it is stored in the CSAT3BH data buffer until it is output to either a data logger or a computer.

Mode 0

In the case where a data logger provides the measurement trigger (Mode 0), the trigger is issued each time the data logger goes through a scan of the program and executes the [CSAT3B\(\)](#) CRBasic instruction. See [CSAT3B\(\)](#) (p. 73) for details on the instruction. When the trigger is executed, it will also prompt the CSAT3BH to output the most recent measurement in the buffer. This means that the data collected in the data logger will be delayed by exactly one scan interval or timestamp.

NOTE:

The earlier generation CSAT3 had a delay of two scan intervals.

The program code can correct for this delay before storing the data to a data table, or the raw time series data can be saved and aligned with other data during post-processing of the data. Once the one scan delay is accounted for, this method of triggering and prompting the CSAT3BH with a data logger is the best way to achieve optimum synchronicity with other fast-response sensors. Because the measurement was triggered according to the data logger clock, the timing is known exactly. If the data logger makes measurements of other fast-response sensors via analog measurement, SDM, or CPI, then the measurements from the CSAT3BH and other sensors can be synchronized precisely.

Mode 1

In the case where the CSAT3BH is self-triggered and filtered, the output data can still be collected by a data logger (Mode 1) using CPI communications. In this case, the data logger will prompt the CSAT3BH for an output each time it executes the [CSAT3B\(\)](#) CRBasic instruction in the program scan. When the data logger prompt is received by the CSAT3BH, it will output the most recent 100 Hz filtered sample in its buffer to the data logger. This filtered data is delayed by a certain time interval (given in [Table 7-2](#) (p. 67)) and should be taken into account when aligning with other fast-response sensors. There are additional synchronicity considerations. Because the measurement was not triggered by the data logger according to its own clock, the sample received by the data logger may have a small synchronicity error between -5 and $+5$ milliseconds.

with respect to the data logger timestamp. The actual error depends on the operational mode and the output rate, as shown in [Table 7-3](#) (p. 71).

NOTE:

Mode 1 (bandwidth filter and data logger prompted sampling) is only compatible with CPI communications.

Modes 2 and 3

If the CSAT3BH measurements are to be self-triggered and output to a computer, as in Modes 2 and 3, an unprompted output operating mode should be selected. Available output rates for the CSAT3BH are 10, 20, 50, or 100 Hz. In unprompted mode, the CSAT3BH will downsample or decimate the 100 Hz buffer data (unfiltered or filtered, depending on whether the user has selected Mode 2 or Mode 3, respectively) to output at the appropriate rate. The unprompted output record is an ASCII string of comma-delimited data terminated by a carriage return and contains the following seven data fields:

- 1) u_x — x-axis wind speed in meters per second ($\text{m}\cdot\text{s}^{-1}$)
- 2) u_y — y-axis wind speed in meters per second ($\text{m}\cdot\text{s}^{-1}$)
- 3) u_z — z-axis wind speed in meters per second ($\text{m}\cdot\text{s}^{-1}$)
- 4) T_s — Sonic temperature in degrees Celsius ($^{\circ}\text{C}$)
- 5) Diagnostic word
- 6) Record counter
- 7) Signature

The record counter is a decimal value that is incremented each record until reaching a maximum value of 255, at which point it starts back over at zero. The counter may be used to ensure each record is not a duplicate of the last and that a record has not been omitted.

The final data field in each record is the signature, a four-character hexadecimal value that is a function of the specific sequence and number of bytes in the output array. The computer may calculate its own signature using each transmitted byte until reaching the signature data field. The computed signature and the transmitted signature are compared. If they match, the data was received correctly. This is very similar to a Cyclic-Redundancy-Check (CRC).

NOTE:

Signature checking is done automatically by a data logger when using SDM or CPI communications and does not require extra programming by the user.

In most situations, a computer computes the signature by reading in the ASCII data and extracting the last four ASCII characters, casting them as Long data type. The signature is then calculated on the data sent from the CSAT3BH, starting with u_x and ending with the counter. All the characters after the counter are not part of the signature. Once the signature is computed using the algorithm below, it is compared to the transmitted signature. If signatures do not match, the data should be disregarded.

The following block of code is an example implementation of the Campbell Scientific signature algorithm in the programming language C. To generate the signature of an output array of bytes, the "seed" needs to be initialized to 0xaaaa and a pointer passed to the first byte of the output array. The number of bytes in the output array should be entered in as the "swath". The returned value is the computed signature.

```
// signature(), signature algorithm.
// Standard signature is initialized with a seed of 0xaaaa.
// Returns signature.
unsigned short signature( unsigned char* buf, int swath, unsigned short seed ) {
unsigned char msb, lsb;
unsigned char b;
int i;
msb = seed >> 8;
lsb = seed;
for( i = 0; i < swath; i++ ) {
    b = (lsb << 1) + msb + *buf++;
    if( lsb & 0x80 ) b++;
    msb = lsb;
    lsb = b;
}
return (unsigned short)((msb << 8) + lsb);
}
```

FIGURE 7-3 (p. 71) shows an example of unprompted output (RS-485 or USB) to a computer. A timestamp for the incoming data record may be assigned by the computer, where the interval between records is 1/unprompted output rate. The data in each unprompted output record will be delayed according to Table 7-3 (p. 71). Even after accounting for the sample delay, a synchronicity error between the computer and the CSAT3BH may still exist, since they each have their own clocks. Table 7-3 (p. 71) shows the possible synchronicity errors for each output rate.

```

|
0.08945,0.06552,0.05726,19.69336,0,5,c3a6
0.10103,0.06517,0.05312,19.70499,0,6,3927
0.09045,0.04732,0.04198,19.71161,0,7,d7e5
0.08199,0.03341,0.03421,19.73416,0,8,4ad9
0.08867,0.03522,0.03378,19.75360,0,9,e314
0.08675,0.02142,0.03289,19.76858,0,10,9b60
0.09035,0.01987,0.03667,19.78433,0,11,931a
0.09960,0.02615,0.04330,19.79236,0,12,14a1
0.09489,0.02513,0.05120,19.79083,0,13,0c0d
0.09513,0.02403,0.05648,19.79037,0,14,c30d
0.10715,0.02723,0.05739,19.78729,0,15,a14c
0.11630,0.03674,0.05579,19.78812,0,16,5cd7

```

FIGURE 7-3. Example of unprompted RS-485 or USB output to computer

Mode	Synchronicity error		
0	0 ms		
1	-5 to +5 ms		
2 and 3	Output rate	10 Hz	0 to 100 ms
		20 Hz	0 to 50 ms
		50 Hz	0 to 20 ms
		100 Hz	0 to 10 ms

7.3.4 Operating mode recommendations

Due to the advantages in making synchronous measurements, Campbell Scientific recommends using a data logger that supports SDM or CPI communications to collect data from the CSAT3BH. If flux measurements are the primary interest, Campbell Scientific further recommends that the CSAT3BH be operated in Mode 0 where the data logger triggers the measurements, no filters are applied, and the data is collected by the data logger. If unaliased spectra are desired for characterization of the system and site, Mode 1 is recommended in which the measurements are self triggered, a filter is applied with a bandwidth that is half the data logger scan rate, and the data is down-sampled by the data logger. If flux measurements and spectral characterizations are of interest, then Campbell Scientific recommends unaliased data using Mode 1, along a sample rate sufficient to capture the high-frequency variations that contribute to fluxes.

7.4 Synchronization with other sensors

As a delay exists between the CSAT3BH measurement and output to a data logger or computer (see Table 7-2 (p. 67)), the CSAT3BH data will be slightly older than the record timestamp (recall

that the timestamp is assigned to the record by the data logger or computer). This delay is not important when calculating covariances between variables from the CSAT3BH since the variables are already synchronized and aligned with one another. However, when covariances are being calculated between CSAT3BH data and data from other fast-response sensors, the time difference must be accounted for. As an example, suppose a data logger is making 10 Hz (100 ms) measurements of a CSAT3BH and an analog sensor such as a fine-wire thermocouple. In the raw data table of the data logger, the timestamp for the thermocouple data will be when the measurement actually took place, whereas the CSAT3BH data will be delayed by 100 ms. Before covariances are calculated, the fine-wire thermocouple data should be lagged by one scan interval (100 ms) so that all data is aligned in time. This lagging of the data can be done online with the data logger, or it is often done offline using computer software.

[Table 7-4](#) (p. 73) shows the measurement lags that should be applied to analog measurements or measurements with no delay in order to align them with CSAT3BH data. The lags shown for Modes 1 and 3 indicate the number of output scans that the analog measurements should be delayed.

For example, in Mode 1 where data is being filtered and then output is prompted by a data logger, if the data logger has a 10 Hz scan rate and the CSAT3BH has been set to use a 5 Hz bandwidth filter, the analog measurements should be delayed by eight data logger scans (eight 100 ms/scan = 800 ms). [Table 7-4](#) (p. 73) also indicates the preferred settings for flux measurements and spectral analysis. As discussed previously, for spectral analysis, the bandwidth should be selected as half the output rate. For flux applications, the output rate or sampling frequency need not be greater than 10 or 20 Hz in order to reduce unwieldy data sets, and the bandwidth may be left fairly wide open (for example, 25 Hz) to ensure high frequency fluxes are retained in the signal.

Table 7-4: Measurement lags (N_{lag}) for analog measurements or measurements with no delay

Mode	Measurement lag (N_{lag})					
0 ^{1/}	1 data logger scan					
2	Unprompted output rate/100 (lag in seconds)					
1 and 3	Lag is in output samples		Output rate (f_{scan})			
			10 Hz	20 Hz	50 Hz	100 Hz
	Bandwidth	5 Hz	8 ^{2/}	16	40	80
		10 Hz	4	8 ^{2/}	20	40
25 Hz ^{1/}		-	-	8 ^{2/}	16	
1/ Wide bandwidth, good for flux applications						
2/ Anti-aliased frequency response, good for spectral analyses						

$$N_{lag} = \frac{f_{scan}}{BW} \times 4 \text{ in output samples}$$

7.5 Data logger programming using SDM or CPI

The **CSAT3B()** CRBasic instructions control and retrieve data from the CSAT3BH. These instructions are available on the CR6, CR1000X, CR800/850, and CR3000 data loggers.

The following sections give specifics about CRBasic instructions.

7.5.1 CSAT3B()

The **CSAT3B()** instruction is the primary instruction used to retrieve anemometer data from the CSAT3BH. This will set the operating mode of the anemometer and retrieve the wind, sonic temperature, and diagnostic information. The instruction requires four parameters that are further described in the following sections:

- Destination
- Bus
- CSAT3BAddress
- CSAT3BMode

The **CSAT3B()** instruction should appear in the main scan of the CRBasic program operating in pipeline mode.

Destination

This variable will store the values returned by the anemometer. The destination variable must be declared as a float (default) with at least five elements. The CSAT3BH returns the following data in response to a measurement trigger:

- u_x — x-axis wind speed in meters per second ($\text{m}\cdot\text{s}^{-1}$)
- u_y — y-axis wind speed in meters per second ($\text{m}\cdot\text{s}^{-1}$)
- u_z — z-axis wind speed in meters per second ($\text{m}\cdot\text{s}^{-1}$)
- T_s — Sonic temperature in degrees Celsius ($^{\circ}\text{C}$)
- Diagnostic word

Bus

This parameter determines whether the communications to the CSAT3BH are done via the SDM or CPI bus. A **0** indicates SDM and a **1** indicates CPI. This parameter must be a constant. If this is set to **0**, the **CSAT3BMode** parameter must also be set to **0** since the SDM protocol does not support Mode 1 operation or the use of bandwidth filters.

CSAT3BAddress

This parameter identifies the unique address of the CSAT3BH on the communication bus. For SDM, this number may be in the range of **1** to **14**. For CPI, this number may be in the range **1** to **120**. This parameter must be a constant.

CSAT3BMode

This parameter controls whether the CSAT3BH will operate in Mode 0 or Mode 1 (as described in [Table 7-1](#) (p. 66)). This parameter must be a constant and may have one of the following values: 0, 5, 10, or 25. [Table 7-5](#) (p. 75) lists the meaning of each of these values.

Code	Description
0	Data logger triggered/no filter/data logger prompted output
5	Self triggered/5 Hz bandwidth filter/data logger prompted output
10	Self triggered/10 Hz band bandwidth filter/data logger prompted output
25	Self triggered/25 Hz band bandwidth filter/data logger prompted output

The SDM protocol does not support Mode 1 operation or use of bandwidth filters. Accordingly, if the **Bus** parameter is set to **0**, indicating SDM communications, this **CSAT3BMode** parameter must also be set to **0**. If the **Bus** parameter is set to **1**, indicating CPI communications, all of the defined values are valid.

7.5.2 CSAT3BMonitor()

The **CSAT3BMonitor()** instruction provides auxiliary information pertaining to the physical condition of the anemometer. This retrieves the internal temperature and relative humidity of the electronics enclosure and also the inclination of the anemometer. The instruction requires three parameters: **Destination**, **Bus**, and **Address**. The **CSAT3BMonitor()** instruction should appear in a slow sequence of the CRBasic program operating in pipeline mode.

Destination

This variable will store the values returned by the anemometer. The destination variable must be declared as a float (default) with at least four elements. The CSAT3BH returns the following data in response to this instruction:

- Electronics temperature in degrees Celsius (°C)
- Electronics relative humidity as a percentage (%)
- Inclinator pitch in degrees (°)
- Inclinator roll in degrees (°)

Bus

This parameter determines whether the communications to the CSAT3BH are done via the SDM or CPI bus. A **0** indicates SDM and a **1** indicates CPI. This parameter must be a constant.

Address

This parameter identifies the unique address of the CSAT3BH on the communication bus. For SDM, this number may be in the range **1** to **14**. For CPI, this number may be in the range **1** to **120**. This parameter must be a constant.

7.5.3 Diagnostic word

The fifth output from the CSAT3BH is the diagnostic word. The diagnostic word describes the status of the anemometer and is useful in filtering data. For example, when the anemometer is locking in on the ultrasonic signals after receiving the acquire signals command, the **NAN** it sends to the data logger for the science data can be filtered out of the statistics based on the diagnostic word.

The diagnostic word is formatted as a simple 32-bit binary word. Each bit in the diagnostic word represents a different warning flag related to the operation of the CSAT3BH. The data logger will display the diagnostic word as a base-10 integer. Viewed in this manner, each of the 32 bits has a different magnitude as a decimal number. The resultant decimal number will be the sum of the decimal magnitudes of each of the bits that are set. [Table 7-6](#) (p. 76) summarizes the CSAT3BH diagnostic word flags.

Bit #	Hex value	Decimal value	Flag name	Description	Troubleshooting
0	0x0001	1	Low Amplitude	Ultrasonic signal is too small	Check for an obstruction in the anemometer path or on the transducer face
1	0x0002	2	High Amplitude	Ultrasonic signal is too large	Check if an obstruction, in the anemometer path or on the transducer face, was removed
2	0x0004	4	Tracking	The signal lock is poor	Check for an obstruction in the anemometer path or on the transducer face
3	0x0008	8	High Delta C	Difference in the speed of sound between the three non-orthogonal axes is greater than $2.360 \text{ m}\cdot\text{s}^{-1}$ ($\sim 4 \text{ }^\circ\text{C}$ @ $25 \text{ }^\circ\text{C}$)	Check if the anemometer path length was altered, or if the anemometer head is structurally damaged

Table 7-6: Diagnostic word flags

Bit #	Hex value	Decimal value	Flag name	Description	Troubleshooting
4	0x0010	16	Acquiring	Indicates that the anemometer is trying to acquire the sonic signal	Check for an obstruction in the anemometer path or on the transducer face, or if a transducer has failed
5	0x0020	32	Low Voltage	The supply voltage to the anemometer is below 9.0 VDC ^{1/}	Check the power supply or investigate whether cable lengths are excessive
6	0x0040	64	Trigger Error	A measurement trigger has not been received for at least 1 sec, or the time interval between triggers is varying by greater than 5%	Check wiring to the data logger, and check the data logger program for the expected trigger rate
7	0x0080	128	Internal Humidity Warning	The relative humidity inside the CSAT3BH block is greater than 80%	Change the internal desiccant canister (see Desiccant (p. 85))
8	0x0100	256	Memory Error	There is a signature mismatch from the calibration file or another section of memory	Resend an OS and/or cal file to the CSAT3BH; contact Campbell Scientific for details

^{1/} 9 V is slightly below the 9.5 V minimum specification described in [Specifications](#) to account for the expected short duration transients.

7.5.4 SDMTrigger()

The [SDMTrigger\(\)](#) is an SDM Input/Output instruction that controls SDM devices that support the group trigger protocol, including the CSAT3BH. Up to 15 group-trigger devices can be connected to the SDM bus. All group-trigger devices are triggered for simultaneous measurements with the [SDMTrigger\(\)](#). The data from each device is retrieved with the appropriate device-specific instruction.

The [SDMTrigger\(\)](#) instruction is unnecessary when using CPI communications because group triggering is integrated and enabled into the CPI protocol. Multiple CPI devices will inherently be synchronized.

7.6 Programming

Programming the CSAT3BH is accomplished by accessing the program for either the CR6 or CR1000X data logger at the downloads section of the CSAT3BH web page

www.campbellsci.com/csat3bh .

7.7 Data logger and CSAT3H heater controller box programs

The CSAT3BH uses a smart heating algorithm to both maintain and clear obstructions from the sonic path. This requires the Campbell Scientific data logger program to contain the proper section of code for control.

Example CRBasic code provided by Campbell Scientific will have these required sections designated with the comment, "Has to be in Logger program".

Failure to maintain these sections of code will cause the heater to not function. If the program or OS of the controller needs updating, the USB port may be used. Additionally, if remote communications are available to the main data logger, the RS-485 link to the controller box may be used to send the program/operating system (see [Sending an OS to the CSAT3H heater controller box](#) (p. 89)).

NOTE:

Do not modify the program running on the control box without first speaking with Campbell Scientific. Contact Campbell Scientific for help if attempting to update the program or operating system of the controller board. Sending a new program to the controller requires a specific procedure. Not following the recommended procedure may result in the program stopping and requiring a trip to the field site to manually load a new operating system or program.

7.8 CSAT3H heater controller output

The CSAT3BH outputs the same data as the CSAT3B; however, additional information provided by the CSAT3H heater controller is also output into the HeaterControlData table. [Table 7-7](#) (p. 79) provides a list of the fields that are output by this table. Additionally, power consumption from the heaters can be viewed within the HeaterPowerData table.

NOTE:

Currently, no logic in the program exists to turn off the heaters under a transducer failure or any condition that would obscure the transducers and not be removed by heating. Both of these conditions will appear as a signal blockage. This could result in a deep draining of a power supply. If such logic is desired, please work with Campbell Scientific to add a timeout into the code.

Table 7-7: CSAT3H heater controller outputs

Variable name	Units	Description
CSAT3H_user_ctrl_on_secs	s	The length of time in the output interval that CSAT3H_user_ctrl_on was set to 1
CSAT3H_ctrl_on_secs	s	The length of time in the output interval that CSAT3H_ctrl_on was set to 1
U_total_Avg	m/s	Total wind speed: an average over the last slow scan intervals in the main data logger
Ts_Avg	°C	Average sonic temperature during the interval
diag_sonic_output_intv	–	Diagnostic word output by the sonic during the interval
press_Avg	hPa	Average ambient pressure during the interval
com_intv	s	Communication interval between the main data logger and CSAT3H heater controller (for example., slow scan interval in main data logger measurements)
T_trnsd_uppr_Avg	°C	Average temperature measured by the thermistor in the elbow of the A' (top) sonic finger
T_trnsd_uppr_Std	°C	Temperature standard deviation measured by the thermistor in the elbow of the A' (top) sonic finger
T_trnsd_lwr_Avg	°C	Average temperature measured by the thermistor in the elbow of the A (bottom) sonic finger
T_trnsd_lwr_Std	°C	Temperature standard deviation measured by the thermistor in the elbow of the A (bottom) sonic finger
T_trnsd_Max	°C	Maximum temperature between the top and bottom transducers
T_trnsd_Min	°C	Minimum temperature between the top and bottom transducers

Table 7-7: CSAT3H heater controller outputs

Variable name	Units	Description
delta_T_trnsds_Max	°C	Difference between the maximum temperature of top and bottom transducers
T_arm_uppr_Avg	°C	Average temperature of the top sonic arm
T_arm_uppr_Std	°C	Temperature standard deviation of the top sonic arm
T_arm_lwr_Avg	°C	Average temperature of the bottom sonic arm
T_arm_lwr_Std	°C	Temperature standard deviation of the bottom sonic arm
T_arm_Max	°C	Maximum temperature between the top and bottom arms
T_arm_Min	°C	Minimum temperature between the top and bottom arms
delta_T_arms_Max	°C	Difference between the maximum temperature of top and bottom arms
T_trnsd_arm_Max	°C	Maximum temperature among all transducer and arm thermistors
set_T_pt_trnsds_Avg	°C	Temperature to which transducers are set to heat; NAN if no heating is needed
set_T_pt_arms_Avg	°C	Temperature to which arms are set to heat; NAN if no heating is needed
T_amb_ctrl	°C	Average ambient temperature measured by the temp/RH probe connected to the CSAT3H heater controller
T_amb_ctrl_Std	°C	Ambient temperature standard deviation measured by the temp/RH probe connected to the CSAT3H heater controller
RH_amb_ctrl	%	Average ambient relative humidity measured by the temp/RH probe connected to the CSAT3H heater controller
T_DP_amb_ctrl	°C	Average ambient dew point temperature determined by the temp/RH probe connected to the CSAT3H heater controller

Table 7-7: CSAT3H heater controller outputs

Variable name	Units	Description
VPD_amb_ctrl_Min	hPa	Minimum vapor pressure deficit determined by the temp/RH probe connected to the CSAT3H heater controller
crrnt_trnsds_Avg	Amps	Average current provided to heat the sonic transducers
pwr_trnsds_Avg	Watts	Average power provided to heat the sonic transducers
crrnt_arms_Avg	Amps	Average current provided to heat the sonic arms
pwr_arms_Avg	Watts	Average power provided to heat the sonic arms
pwr_trnsds_arms_Avg	Watts	Average total power provided to heat the entire sonic
trnsd_heater_on_secs	s	Time during the interval that the transducers were heated
trnsd_heater_ctrl_secs	s	Time during the interval that the CSAT3H heater controller was given the green light by the main data logger to provide heat to the transducers
trnsd_heater_fail_secs	s	Time during the interval that the transducer heaters failed to heat
arm_heater_on_secs	s	Time during the interval that the arms were heated
arm_heater_ctrl_secs	s	Time during the interval that the CSAT3H heater controller was given the green light by the main data logger to provide heat to the arms
arm_heater_fail_secs	s	Time during the interval that the arm heaters failed to heat
trnsd_ice_wet_lck_sec	s	Time in which one or more transducers was not transmitting signal due to ice/dew as determined by diagnostics and ambient temperature/dew point
heating_inaplcbl_sec	s	Time in which one or more transducers was not transmitting signal for potentially unknown reasons or reasons beyond ice/dew
secs_blocked_Max	s	Maximum consecutive seconds the transducers were unable to establish a signal
mV_real_trnsds_Max	mV	Maximum millivolt signal CSAT3H heater controller used to determine how much heat to apply to the transducers

Variable name	Units	Description
mV_real_arms_Max	mV	Maximum millivolt signal CSAT3H heater controller used to determine how much heat to apply to the arms
wnd_spd_fctr_Max	–	Maximum multiplier applied to heaters as conditions become more windy, requiring more heat (value of 0 to 7)
T_boost_mult_Max	–	Maximum multiplier applied to heaters under certain conditions that require more heat (value of 0 to 16)
T_Panel_CR300_Avg	°C	Average internal temperature of the CSAT3H heater controller
volt_batt_CR300_Min	V	Minimum battery voltage supplied to the CSAT3H heater controller

8. Maintenance and troubleshooting

8.1 General maintenance

With no moving parts, maintenance of the CSAT3BH is minimal and limited to the following:

- Replacing the desiccant canister
- Monitoring diagnostics and measurement offsets to determine when factory recalibration is needed
- Monitoring diagnostics to assure battery bank for both 12 and 24 VDC power sources have sufficient charge
- Replacing the desiccant pack within the CSAT3H heater electronics enclosure annually

The following sections address these maintenance activities.

CAUTION:

The cover plate to the CSAT3BH electronics should only be removed by qualified technicians at the factory. When covered, the electronics are well protected against transient voltages during handling and operation. Once uncovered, however, they are highly sensitive to electrostatic discharge. There are no user-serviceable components beneath the cover plate. Opening this will void the warranty on the anemometer.

CAUTION:

Never open the CSAT3H heater electronics enclosure except to replace desiccant. The enclosure is secured with four screws in each corner of the box. As exposed electronics are housed within the controller box, exposing the board to electrostatic discharge or allowing it to come into contact with water could cause damage.

8.2 Sonic wicks

Ultrasonic anemometers are unable to measure wind when water droplets completely obscure the face of the transducers. Campbell Scientific algorithm Version 5 along with sonic wicks (shown in [FIGURE 8-1](#) (p. 84)) improve transducer performance in rainy conditions. Under certain conditions, the wicking properties of the sonic wicks may not be adequate. In these circumstances, a sonic anemometer may report diagnostic error conditions or erroneous data until the water droplets evaporate or are manually removed. Droplets can be removed by dabbing a cotton swab or tissue on the face of the transducer.

If site conditions are such that the wicks are unnecessary, gently remove the wicks from the transducers, taking care not to damage or peel the matching layer (rubber tips) from the brass housing of the transducers. Remove the wicks during the winter, as the wicks will accumulate snow or freezing rain to the point where the transducer face will be obscured.

The Spare Sonic Wicks Kit consists of three top wicks, three bottom wicks, and an installation tool (see [FIGURE 8-2](#) (p. 84)). The installation tool is used by placing a wick over the angled end of the tool, placing the straight end of the tool gently against the transducer face, and sliding the wick down the tool onto the transducer.

CAUTION:

Lightly dab the face of the transducer to remove water droplets. Applying excessive force on the face of the transducer may damage the matching layer. Do not attempt to remove ice or frost without melting it first by gently warming the anemometer.

If the wicks are to be permanently installed at the site, ensure that the wicks are located in the proper position. [FIGURE 8-1](#) (p. 84) shows the proper orientation of the transducer wicks. The top wick must be flush with the transducer face, with the wick tail located at the lowest point of the

transducer (FIGURE 8-1 (p. 84), left). The end of the bottom transducer wick must extend above the transducer face by between one-half and one mesh lines (FIGURE 8-1 (p. 84), right). The wicks will stay in place; it is not necessary to use an adhesive.

Replacement top wicks and bottom wicks can be purchased from Campbell Scientific. A complete set of wicks for one sonic anemometer consists of three top wicks and three bottom wicks.

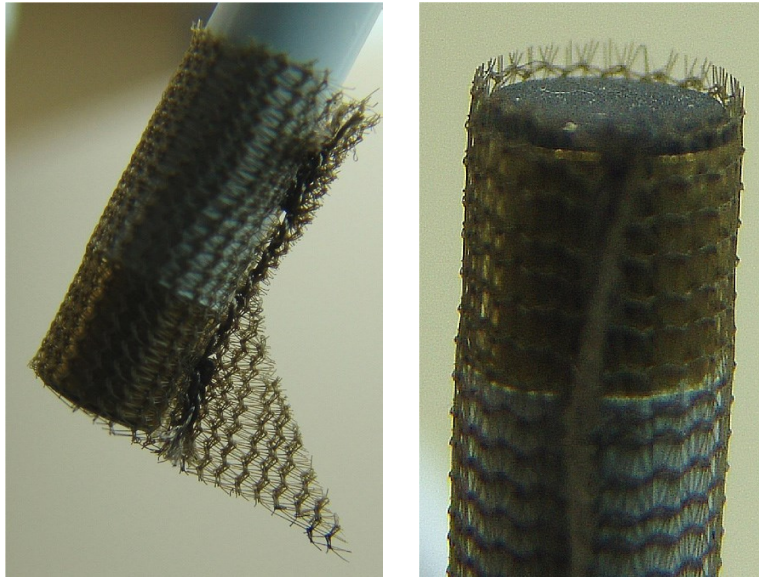


FIGURE 8-1. Proper location of the sonic top wick (left) and bottom wick (right)



FIGURE 8-2. Spare Sonic Wicks Kit contents

8.3 Desiccant

To prevent liquid water from coming in contact with any electronics, the internal humidity must be maintained at non-condensing levels. The CSAT3BH has an on-board relative humidity sensor that continuously monitors the humidity inside the enclosure. This humidity ranges between 0 and 100%. As temperature decreases, the capacity of air to hold water also decreases, and the relative humidity will increase even if no additional water has been introduced into the closed system. As the relative humidity approaches 100%, condensation will begin to form on the internal surfaces. Other electronic components, however, are not equipped with sensors and, therefore, the user must implement some maintenance plan in which desiccant changeout is either done as routine maintenance or by routine checks of the indicator card inside the enclosure.

The CSAT3BH has a cavity to hold a replaceable desiccant canister that removes water from the air (see [FIGURE 8-3](#) (p. 86)). Water molecules will unavoidably ingress into the electronics over time, so the internal humidity of the CSAT3BH head should periodically be checked. This can be done automatically with a data logger if the data logger program uses the [CSAT3BMonitor\(\)](#) instruction in *CRBasic Editor*, or manually by connecting a CSAT3BH to a computer using the USB cable and then launching the *Device Configuration Utility*. Under the **Settings Editor** tab of the utility, there is secondary tab for **Real-Time Data**, where the internal humidity measurement will be displayed along with various other measurements.

If monitoring shows the internal humidity of the CSAT3BH rising above 50%, including during nighttime cooling cycles, the desiccant should be replaced with canisters that can be purchased from Campbell Scientific. The small canister holds desiccant and is installed on the underside of the anemometer block inside the brass screw cap (see [FIGURE 8-3](#) (p. 86)). Use a large flat-headed screwdriver to unscrew the cap and remove the canister. Replace the old canister with an unused one.

The new canister should appear blue in color. A pink-hued canister indicates that moisture has been absorbed, and the canister should be discarded and replaced with a new one. When replacing the brass screw cap, ensure the cap is tightened until the head of the screw is flush with the housing and the o-ring cannot be seen.

NOTE:

Replacement desiccant canisters are shipped in a vacuum-sealed bag. The bag should not be opened until the canisters are to be inserted into the anemometer block.

Desiccants are shipped with an expiration date. The expiration date reflects the date by which the desiccant should be properly installed in the instrument.



FIGURE 8-3. Exploded view of CSAT3BH desiccant canister

8.4 Calibration

The CSAT3BH is calibrated at the factory over the temperature range of -40 to 50 °C, as sonic transducer response is a function of temperature. Any measurements taken at temperatures outside of this range will be suspect.

The CSAT3BH does not require field calibration; however, it may require a factory recalibration every few years. An indication that the CSAT3BH is due to be returned to the factory for recalibration is when diagnostic flags are persistent under dry conditions with little to no wind and with no obstruction in the ultrasonic paths. A wind offset greater than the specifications found in [Specifications](#) (p. 17) is another indication that a recalibration is due. To check for wind offset, refer to [Test for wind offset](#) (p. 86).

8.4.1 Test for wind offset

Testing wind offset on a CSAT3BH requires creating an environment where wind is absent. Because it is difficult to do this in the field, wind offset data from the CSAT3BH should be collected in a field office or the lab. A zero-wind environment can be created with a kitchen waste bin liner. The following steps should be taken to test the CSAT3BH for wind offset.

1. Mount the head using the horizontal mount boom (as described in [Mounting](#) (p. 31)), or hang the head from the block that supports the CSAT3BH upper and lower arms. Do not

lay the CSAT3BH head on its side or balance it on the transducers, as this will affect its measurements.

2. Cover the CSAT3BH head with a medium (13-gallon) kitchen waste bin liner. Close the opening of the liner by folding, taping, or tying, to prevent air from moving in and out of the liner. Temporarily disable the HVAC system in the room, or cover air vents that may cause air drafts to pass by the CSAT3BH. Ensure that the liner does not obstruct any of the three CSAT3BH sonic paths.
3. Connect the CSAT3BH power and communications cable to the data logger referring to [Communications](#) (p. 44). Connect to the data logger with *LoggerNet* or *PC400*.
4. Use the real-time monitoring graph display to create two graphs.
 - a. On the first graph, add the u_x and u_y wind components and set the y limits from -0.08 to 0.08 as shown in [FIGURE 8-4](#) (p. 87).
 - b. On the second graph, add the u_z wind component and set the y limits from -0.04 to 0.04 as shown in [FIGURE 8-5](#) (p. 88).
 - c. For both graphs, set **Graph Width** to 1 minute and **Update Interval** to 1 second.

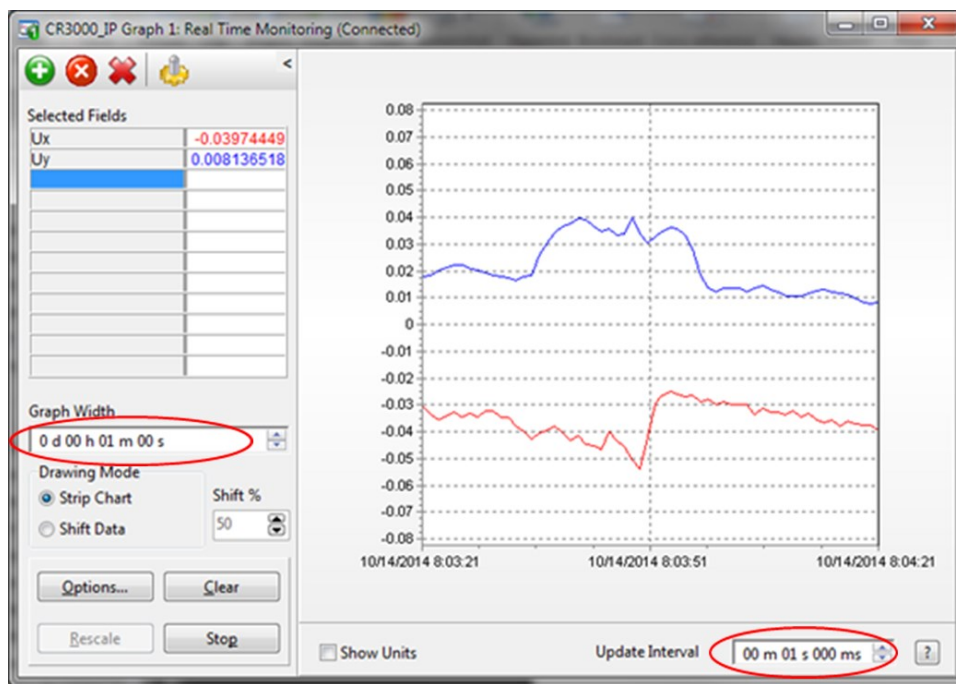


FIGURE 8-4. CSAT3BH real-time data with 1 sec update and u_x and u_y wind components graphed

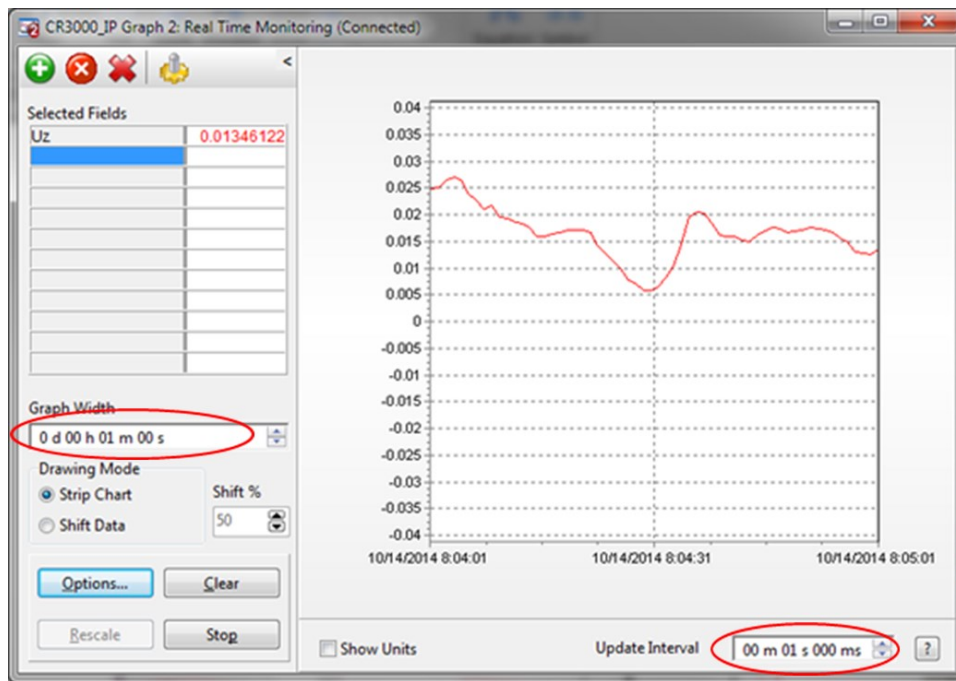


FIGURE 8-5. CSAT3BH real-time data with 1 sec update and u_z wind component graphed

Graph 1 minute of wind data from the CSAT3BH while it is in the zero-wind environment. The wind offset should be less than $\pm 8 \text{ cm}\cdot\text{s}^{-1}$ ($0.08 \text{ m}\cdot\text{s}^{-1}$) for u_x and u_y , and less than $\pm 4 \text{ cm}\cdot\text{s}^{-1}$ ($0.04 \text{ m}\cdot\text{s}^{-1}$) for u_z . If the CSAT3BH wind offset is greater than these specifications, contact Campbell Scientific for an RMA number to recalibrate the CSAT3BH.

NOTE:

When returning a CSAT3BH for factory recalibration or repair, it is important to ship the unit with the foam inserts (see [Sonic carrying case](#) (p. 7)) provided from the factory.

8.5 Troubleshooting

Most problems that occur with the CSAT3BH will generate a flag in the diagnostic word that are set high (see [Diagnostic word](#) (p. 76) and [Table 7-6](#) (p. 76)). It is normal to see occasional sonic flags being set due to precipitation, insects, spider webs, birds, etc., that pass through one or more of the sonic paths and obstruct the signal. If diagnostic flags are persistently high, however, this could indicate a more serious problem. In the case that diagnostic flags are persistent, troubleshoot with the following steps:

1. Perform a visual inspection of the CSAT3BH. Make sure it is clear from anything that might obstruct the sonic signal. Check for signs that the geometry of the arms has changed in any way, possibly from an impact from another object.
2. Check all wiring connections between the CSAT3BH and data logger.
3. Check to see if the diagnostic flags are still high.
4. If diagnostic flags persist, remove the CSAT3BH from the site and perform a zero-wind offset as described in [Test for wind offset](#) (p. 86). Check to see if the diagnostic flags are any different once inside the laboratory.
5. In case the diagnostic flags are related to a bug or corruption of the OS, send a new OS following the instructions in [Sending an OS to the CSAT3BH](#) (p. 90).

If the problems are still unresolved, contact Campbell Scientific. If possible, be prepared to send a file of CSAT3BH output data, including the diagnostic word, to Campbell Scientific. If it is determined that the unit must be returned to the factory for recalibration and/or repair, an RMA will be required (see [Returning the CSAT3BH](#) (p. 90)).

8.5.1 Troubleshooting CSAT3H heater controller box issues

The CSAT3H heater controller box passes heater information to the CR6 and is stored within the **HeaterControlData** ([Table 7-7](#) (p. 79)). These data can be used to troubleshoot how well the heaters are functioning. Two diagnostics are triggered if there are potential heater failures: **HeaterFailArm** and **HeaterFailTransducer**. If either of these diagnostics is set to **1**, this is an indication that a heater or thermistor has potentially failed, and the user should contact Campbell Scientific.

If communication gets interrupted between the CR6 and CSAT3H heater controller box for more than 15 minutes, heater functionality will cease until communication between the two has been re-established. If this problem persists, contact Campbell Scientific.

8.5.2 Sending an OS to the CSAT3H heater controller box

To send an operating system (OS) to the CSAT3H controller box remotely and via USB, follow these steps:

1. Go to **File Control** on the controller.
2. Click **OS Loader**.
3. Select **Run Now**.
4. Press **OK**.

5. Press **SEND** and select the program or OS you want to upload to the controller and choose **Run Now, Preserve data if no table changed**, and then click **OK**.

8.5.3 Sending an OS to the CSAT3BH

To send an OS to the CSAT3BH, follow these steps:

1. Go to the downloads section of the CSAT3BH web page (www.campbellsci.com/cs3bh) to download the latest version of the CSAT3BH OS to your computer.
2. Connect to the CSAT3BH via USB and launch the *Device Configuration Utility* as described in [Settings](#) (p. 24).
3. After connecting to the CSAT3BH, click the **Send OS** tab at the top of the *Device Configuration Utility* main screen. Click the **Start** button at the bottom of the page, select the .obj file that you downloaded from the Campbell website, and click **Open**. The OS will then be sent, followed by a confirmation message that it was loaded properly.

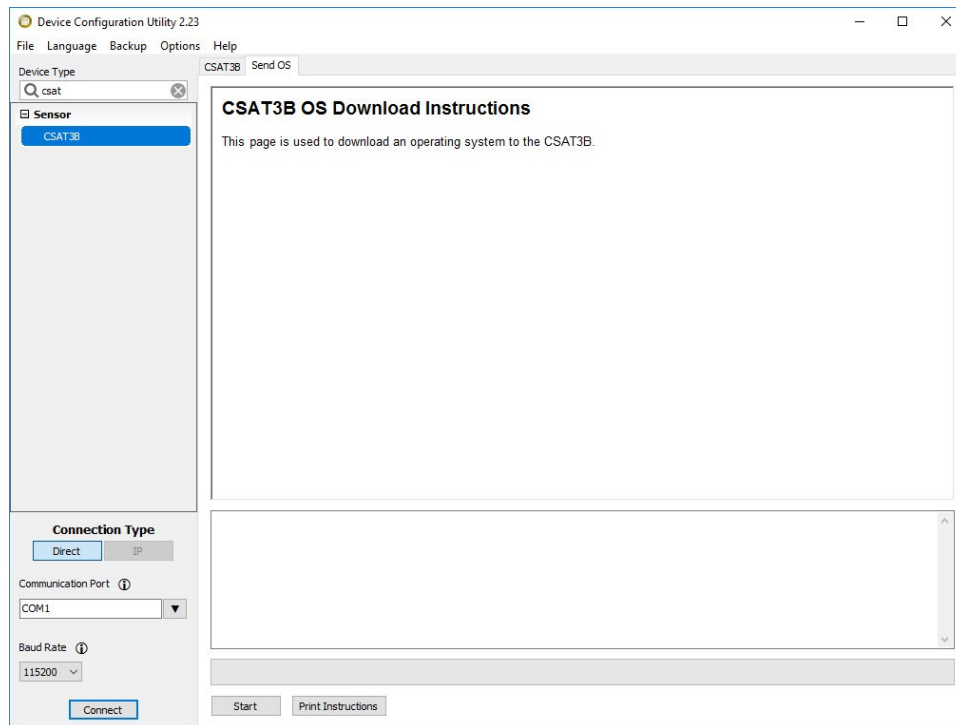


FIGURE 8-6. The Send OS screen in the *Device Configuration Utility*

8.6 Returning the CSAT3BH

If returning the CSAT3BH either for calibration or repair is necessary, please follow the detailed instructions provided in the [Assistance](#) section at the end of this manual, which gives instructions

for generating an RMA number. If additional help is needed, please contact Campbell Scientific. When preparing the CSAT3BH for shipment, be sure to package it in the same foam in which it was sent. If the foam cannot be found, new foam should be ordered from Campbell Scientific before returning the unit.

9. References

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Appendix A. CSAT3BH orientation

A.1 Determining true north and sensor orientation

The orientation of the sonic anemometer negative x-axis is found by reading a magnetic compass and applying the site-specific correction for magnetic declination, where the magnetic declination is the number of degrees between true north and magnetic north. Magnetic declination for a specific site can be obtained from a USGS map, local airport, or through a NOAA web calculator ([Online magnetic declination calculator](#) (p. 93)). A general map showing magnetic declination for the contiguous United States in 2015 is shown in [FIGURE A-1](#) (p. 92).

Declination angles east of true north are reported as positive values and are subtracted from 360 (0) degrees to get true north as shown in [FIGURE A-2](#) (p. 93). Declination angles west of true north are reported as negative values and are subtracted from 0 (360) degrees to get true north as shown in [FIGURE A-3](#) (p. 93). Note that when a negative number is subtracted from a positive number, the resulting arithmetic operation is addition.

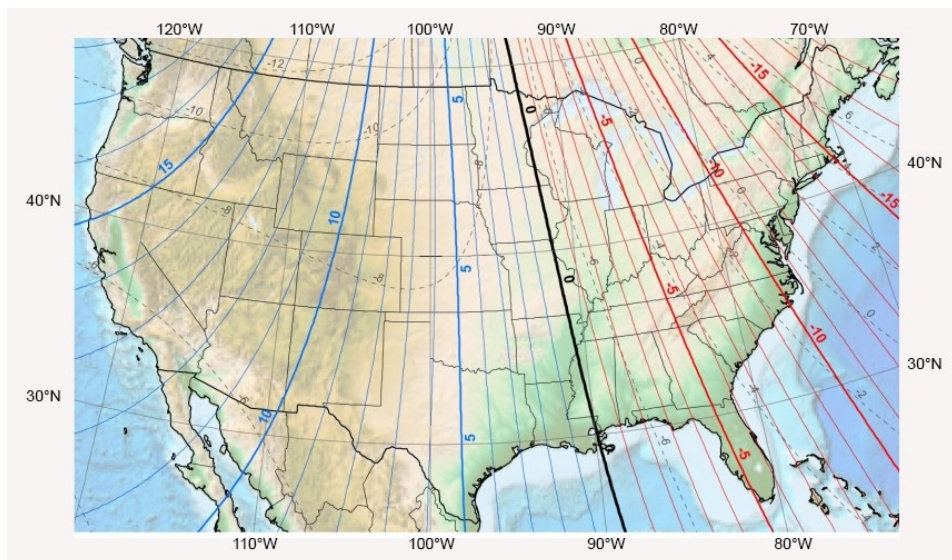


FIGURE A-1. Magnetic declination for the contiguous United States (2015)

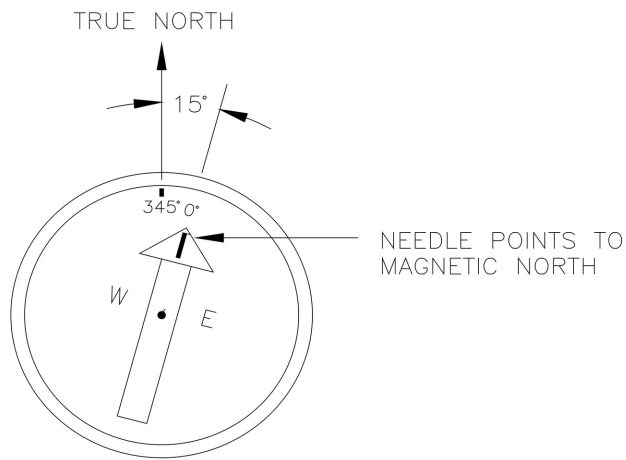


FIGURE A-2. Declination angles east of true north are subtracted from 360 to get true north

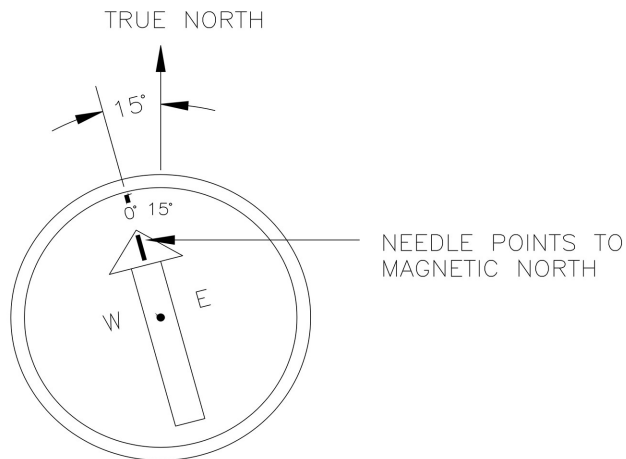


FIGURE A-3. Declination angles west of true north are subtracted from 0 to get true north

A.2 Online magnetic declination calculator

The magnetic declination web calculator published by the NOAA Geophysical Data Center is available at the following URL: <https://www.ngdc.noaa.gov/geomag-web/#declination>. Enter the latitude, longitude, date, and the format you wish to view the data. Once entered, click **Calculate** to determine the declination (FIGURE A-4 (p. 94)).

NOAA NATIONAL CENTERS FOR ENVIRONMENTAL INFORMATION
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NOAA > NESDIS > NCEI (formerly NGDC) > Geomagnetism

Magnetic Field Calculators

Declination | U.S. Historic Declination | Magnetic Field | Magnetic Field Component Grid

Magnetic Declination Estimated Value

Declination is calculated using the most recent World Magnetic Model (WMM) or the International Geomagnetic Reference Field (IGRF) model. For 1590 to 1900 the calculator is based on the *gufm1* model. A smooth transition from *gufm1* to IGRF was implemented from 1990 to 1999. Declination results are typically accurate to 30 minutes of arc, but environmental factors can cause magnetic field disturbances. For more information click the information link.

Calculate Declination

Latitude: S N
 Longitude: W E

Model: WMM (2014-2019) IGRF (1590-2019)

Date: Year Month Day

Result format: HTML XML CSV PDF

Declination

Model Used:	WMM2015
Latitude:	41.7640593° N
Longitude:	111.8573484° W
Date	Declination
2018-11-09	11.47° E ± 0.36° changing by 0.11° W per year

NOAA > NESDIS > NCEI (formerly NGDC) > Geomagnetism

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FIGURE A-4. Online magnetic declination calculator with inputs and output for Logan, UT, USA

The declination for Logan, UT, USA is 11.47° E. Therefore, true north is $360^\circ - 11.47^\circ = 348.53^\circ$. So when looking at a compass at this location, true north is located at 348.53°, not 360°. Declination results are typically accurate to 30 minutes of arc, but environmental factors can cause magnetic field disturbances.

Appendix B. CSAT3BH measurement theory

B.1 Theory of operation

B.1.1 Wind speed

Each axis of the CSAT3BH pulses two ultrasonic signals in opposite directions. The time of flight of the first signal (out) is given by:

$$t_o = \frac{d}{c + u_a} \quad \text{Eq. 1}$$

and the time of flight of the second signal (back) is given by:

$$t_b = \frac{d}{c - u_a} \quad \text{Eq. 2}$$

where:

t_o = time of flight out along the transducer axis

t_b = time of flight back, in the opposite direction

u_a = wind speed along the transducer axis

d = distance between the transducers

c = speed of sound

The wind speed (u_a) along any axis can be found by inverting the preceding relationships, then subtracting Eq. 2 (p. 95) from Eq. 1 (p. 95) and solving for u_a .

$$u_a = \frac{d}{2} \left[\frac{1}{t_o} - \frac{1}{t_b} \right] \quad \text{Eq. 3}$$

The wind speed is measured on all three non-orthogonal axis to give u_a , u_b , and u_c , where the subscripts a, b, and c refer to the non-orthogonal sonic axes.

The non-orthogonal wind speed components are then transformed into orthogonal wind speed components (u_x , u_y , and u_z) with the following:

$$\begin{bmatrix} u_x \\ u_y \\ u_z \end{bmatrix} = A \begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} \quad \text{Eq. 4}$$

where:

A = a 3 x 3 coordinate transformation matrix that is unique for each CSAT3BH and is stored in ROM memory

B.1.2 Temperature

The sonically determined speed of sound is given in Eq. 5 (p. 96) and was found from the sum of the inverses of Eq. 1 (p. 95) and Eq. 2 (p. 95). The CSAT3BH corrects online for the effect of wind blowing perpendicular to the sonic path. No additional off-line corrections are required as suggested by Liu, Peter, and Foken (2001).

$$c = \frac{d}{2} \left[\frac{1}{t_o} + \frac{1}{t_b} \right] \quad \text{Eq. 5}$$

The speed of sound in moist air is a function of temperature and humidity and is given by:

$$c^2 = \gamma P / \rho = \gamma R_d T_v = \gamma R_d T (1 + 0.61q) \quad \text{Eq. 6}$$

where:

γ = ratio of specific heat of moist air at constant pressure to that at constant volume

P = pressure

ρ = air density

R_d = gas constant for dry air

T_v = virtual temperature

T = air temperature

q = specific humidity defined as the ratio of the mass of water vapor to the total mass of air (as in Kaimal and Gaynor 1991; Wallace and Hobbs 2006)

Note that γ is a function of specific humidity. It would be convenient if the effects of humidity could be consolidated into one term.

The specific heats for moist air at constant pressure and volume are given by:

$$\begin{aligned} C_p &= qC_{pw} + (1 - q)C_{pd} \\ &= C_{pd} (1 + 0.84q) \end{aligned} \tag{Eq. 7}$$

$$\begin{aligned} C_v &= qC_{vw} + (1 - q)C_{vd} \\ &= C_{vd} (1 + 0.93q) \end{aligned} \tag{Eq. 8}$$

where, at constant pressure and volume, respectively (Fleagle and Businger 1980):

C_p and C_v = specific heat of moist air

C_{pw} and C_{vw} = specific heat of water vapor

C_{pd} and C_{vd} = specific heat of dry air

Substitute Eq. 7 (p. 97) and Eq. 8 (p. 97) into Eq. 6 (p. 96) and ignore the higher order terms. This yields

$$c^2 = \gamma_d R_d T_s = \gamma_d R_d T (1 + 0.51q) \tag{Eq. 9}$$

where:

T_s = sonic virtual temperature

γ_d = ratio of specific heat of dry air at constant pressure to that at constant volume (Fleagle and Businger 1980; Kaimal and Gaynor 1991; Kaimal and Businger 1963; Schotanus, Nieuwstadt, and de Bruin 1983)

With Eq. 9 (p. 97), the effect of humidity on the speed of sound is included in the sonic virtual temperature.

The sonic virtual temperature, in degrees Celsius, is given by Eq. 10 (p. 97), where $\gamma_d = 1.4$ and $R_d = 287.04 \text{ JK}^{-1} \text{ kg}^{-1}$.

$$T_s = \frac{c^2}{\gamma_d R_d} - 273.15 \tag{Eq. 10}$$

B.2 References

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- **Do not climb** tripods or towers at any time, and prohibit climbing by other persons. Take reasonable precautions to secure tripod and tower sites from trespassers.
- Use only manufacturer recommended parts, materials, and tools.

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- **You can be killed** or sustain serious bodily injury if the tripod, tower, or attachments you are installing, constructing, using, or maintaining, or a tool, stake, or anchor, come in **contact with overhead or underground utility lines**.
- Maintain a distance of at least one-and-one-half times structure height, 6 meters (20 feet), or the distance required by applicable law, **whichever is greater**, between overhead utility lines and the structure (tripod, tower, attachments, or tools).
- Prior to performing site or installation work, inform all utility companies and have all underground utilities marked.
- Comply with all electrical codes. Electrical equipment and related grounding devices should be installed by a licensed and qualified electrician.
- Only use power sources approved for use in the country of installation to power Campbell Scientific devices.

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- Exercise extreme caution when performing elevated work.
- Use appropriate equipment and safety practices.
- During installation and maintenance, keep tower and tripod sites clear of un-trained or non-essential personnel. Take precautions to prevent elevated tools and objects from dropping.
- Do not perform any work in inclement weather, including wind, rain, snow, lightning, etc.

Maintenance

- Periodically (at least yearly) check for wear and damage, including corrosion, stress cracks, frayed cables, loose cable clamps, cable tightness, etc. and take necessary corrective actions.
- Periodically (at least yearly) check electrical ground connections.

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- Be aware of fire, explosion, and severe-burn hazards.
- Misuse or improper installation of the internal lithium battery can cause severe injury.
- Do not recharge, disassemble, heat above 100 °C (212 °F), solder directly to the cell, incinerate, or expose contents to water. Dispose of spent batteries properly.

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