FluoreSens™10

Sun-Induced Chlorophyll Fluorescence (SIF)
Measurement System

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About this manual

Please note that this manual was produced by Campbell Scientific Inc. primarily for the North American market. Some spellings, weights and measures may reflect this. In addition, while most of the information in the manual is correct for all countries, certain information is specific to the North American market and so may not be applicable to European users. Differences include the U.S. standard external power supply details where some information (for example the AC transformer input voltage) will not be applicable for British/European use. Please note, however, *that when a power supply adapter is ordered from Campbell Scientific it will be suitable for use in your country*.

Reference to some radio transmitters, digital cell phones and aerials (antennas) may also not be applicable according to your locality. Some brackets, shields and enclosure options, including wiring, are not sold as standard items in the European market; in some cases alternatives are offered.

Recycling information for countries subject to WEEE regulations 2012/19/EU

At the end of this product's life it should not be put in commercial or domestic refuse but sent for recycling. Any batteries contained within the product or used during the products life should be removed from the product and also be sent to an appropriate recycling facility, per The Waste Electrical and Electronic Equipment (WEEE) Regulations 2012/19/EU. Campbell Scientific can advise on the recycling of the equipment and in some cases arrange collection and the correct disposal of it, although charges may apply for some items or territories. For further support, please contact Campbell Scientific, or your local agent.

Table of contents

1. Introduction

FluoreSens$_{TM}$10 is a system that measures sun-induced chlorophyll fluorescence (SIF) in plants during photosynthesis by collecting downwelling irradiance and upwelling reflected solar radiation signals from vegetation required for SIF retrieval. The system includes a high-resolution spectrometer QE Pro (Ocean Insight, Largo, FL, USA) that measures radiation signals between 650 and 800 nm, observing the SIF signal within the O_2A and O_2B oxygen absorption bands. To perform these measurements, the FluoreSens 10 uses a fiber optic cable, motor, and data logger.

> **NOTE:**
> A second Flame spectrometer for measuring vegetation indices that covers the range from 350 to 1000 nm can also be added.

The main potential application of FluoreSens 10, when combined with an eddy covariance system, is to estimate gross primary productivity (GPP) of CO_2 and assist in partitioning the net ecosystem exchange of carbon dioxide into component fluxes. It can also be used as a standalone system in monitoring vegetation health, performing stress monitoring, detecting early stress in crops and vegetation, and providing advanced warning for drought and fire risk assessment.

The principal design of the system was led by Dr. Lianhong Gu of the Oak Ridge National Laboratory (see Licensed materials [p. 41] and References [p. 42]). Several component modifications and/or selections were made specifically for FluoreSens 10 in order to lower costs, improve space management, improve manufacturability, meet required safety and EMI compliance, and improve the movement of the fiber optic cables.

2. Precautions

- READ AND UNDERSTAND the Safety section at the back of this manual.

- The FluoreSens 10 system has a heavy enclosure that houses highly sensitive and precise spectrometer(s). As it is a precision scientific instrument, it must be handled with care.

- **DO NOT BEND** the optical fibers below a radius of 8 cm. A lower radius will alter the calibration, and a narrow bending can break the fiber.

- Do not modify or attempt to repair the FluoreSens 10 unit without consulting Campbell Scientific.

2.1 Hazards

2.1.1 Electrical hazards

DANGER:
To prevent electrical shock or potential danger, turn off the main power supply before connecting or replacing the battery. Failure to adhere to this imperative precautionary measure may result in serious injury or even loss of life. Additionally, ensure that barriers with adequate insulation are installed on all AC lines for enhanced safety. These barriers serve as protective measures against accidental contact with live wires and minimize the risk of electrical hazards.

Furthermore, it is strongly recommended that the AC connection, including battery installation or replacement, be carried out by a licensed electrician.

2.1.2 Mechanical hazards

- Instability: Ensure that the tower is properly installed and securely fastened to prevent tipping. Improper installation may result in instability, causing potential hazards. Also, ensure that the SIF enclosure is securely mounted to avoid damage or enclosure separation.
- Erected object fall or collapse: Use the mounting hardware to securely mount the motor.

DANGER:
Two-person assistance is required for installation to prevent drops and falls of the enclosure (~ 50 lbs) and fiber guide.

DANGER:
Exercise caution when operating the moving arm to avoid potential injury or accidents.

2.1.3 Condensation hazard

Condensation on the cooled areas of the thermoelectric cooler (TEC) and secondary equipment can lead to potential hazards and damage to both the TEC and secondary equipment if the condensate drains onto them. The use of desiccants is recommended to prevent or eliminate the condensate.

3. Initial inspection

Upon receipt of the FluoreSens 10, inspect the packaging and contents for damage. File damage claims with the shipping company.

Immediately check package contents against shipping documentation. Contact Campbell Scientific about any discrepancies.

3.1 Items included

The following items ship with the FluoreSens 10:

- Enclosure with QE Pro spectrometer and CR1000X data logger
- Fiber optic cable (5 m)
- Guide assembly with motor
- 16 GB microSD card
- Cosine corrector
- 18 ft 4 AWG copper grounding wire
- Calibration sheet for the QE Pro spectrometer (inside enclosure housing)
- Quick Deploy Guide

3.2 Optional accessories

The following optional accessories are available for purchase:

- CR1000KD
- Flame-T (Toshiba) Spectrometer
- SN500SS Net Radiometer
- HL-3P-CAL Radiometrically Calibrated Tungsten Halogen Light Source (Ocean Insight Inc., Dunedin, FL, USA)
- Mounting hardware

4. Overview

4.1 FluoreSens 10 system components

Figure 4-1. FluoreSens 10 with fiber guide

> **NOTE:**
> The thick cable with a 5-pin connector provides power to the motor. The thin cable is for the encoder.

4.1.1 FluoreSens 10 system enclosure

The enclosure includes several components: a power supply, TEC, data logger, and spectrometer (s)*. The spectrometer is housed inside an insulated enclosure (see Figure 4-2 [p. 5]). This protective covering helps to regulate and stabilize the temperature inside the enclosure, ensuring optimal performance of the spectrometer.

*Note: An optional spectrometer, with a spectral range of 350 to 1000 nm, can be added to measure vegetative indices.
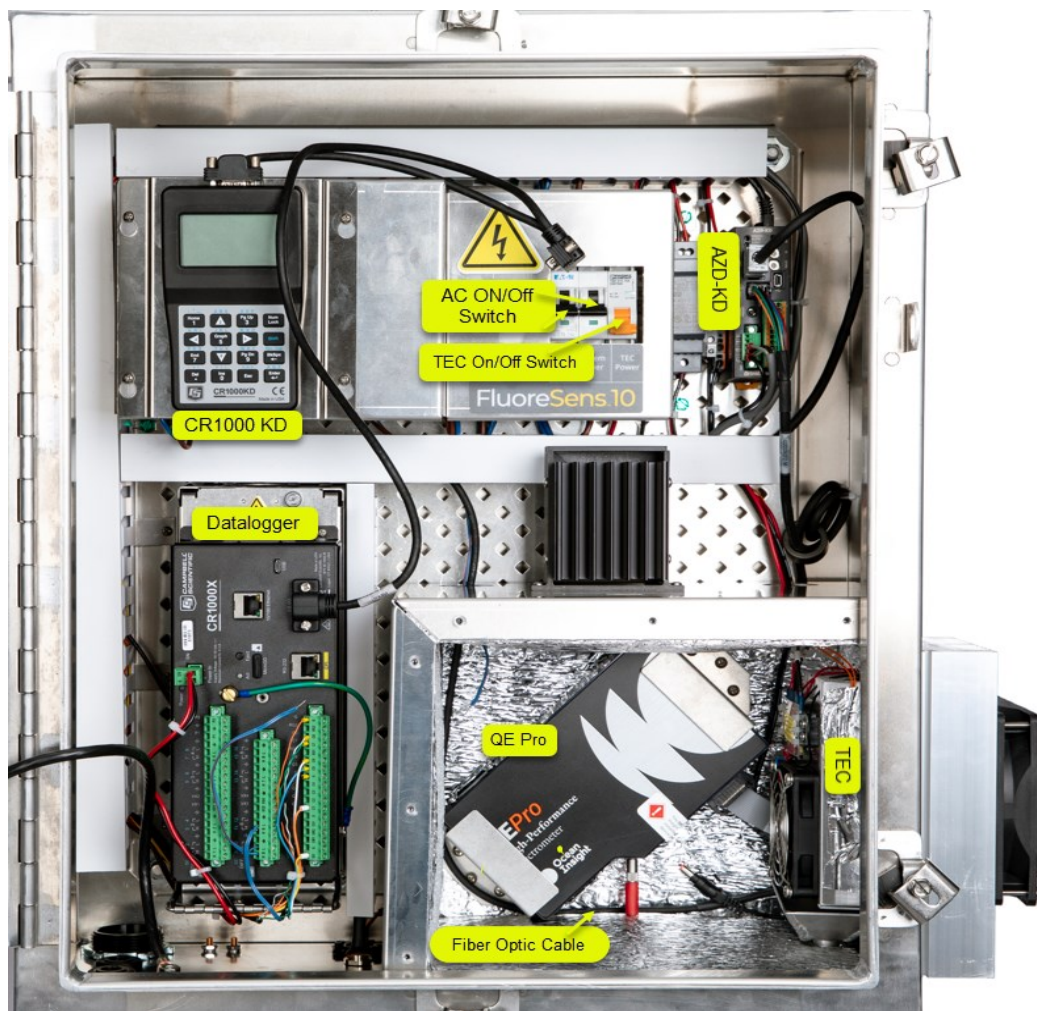
Figure 4-2. FluoreSens 10 enclosure
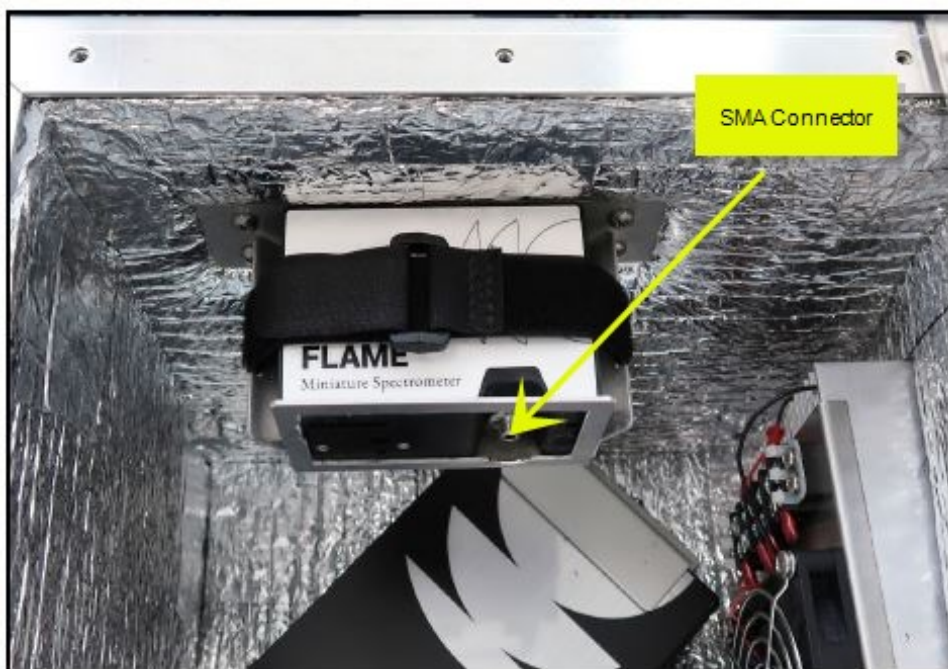
Figure 4-3. FluoreSens 10 with QE Pro and Flame-T spectrometers

Figure 4-4. Bottom of enclosure

4.1.2 Spectrometer(s)

The FluoreSens 10 consists of one high-resolution, high-sensitivity spectrometer (QE Pro, Ocean Insight Inc., Dunedin, FL, USA). Additionally, a Flame spectrometer for measuring vegetation indices is available for purchase.

Figure 4-5. Flame-T spectometer

4.1.3 CR1000KD

The CR1000KD is a portable keyboard and display screen for Campbell Scientific data loggers that have a CSI/O port. It can provide a better user experience in the field by allowing users to interact directly with the data logger without the need for an external computer. The CR1000KD can be used for real-time data viewing, manual data entry, system diagnostics, troubleshooting, and controlling calibration routines. Its intuitive navigation menu enhances system setup, calibration, maintenance, and data validation during field operations.

4.1.4 TEC

To reduce thermal noise and optimize performance, it is necessary for the CCDs (charge-coupled devices) of spectrometers to operate at subzero temperatures. QE Pros employ an internal TEC that can lower the temperature of the CCD array by up to 40 °C compared to the surrounding temperature. An external TEC is used to control the temperature of spectrometer surroundings inside the enclosure. By using these two nested TECs, the CCD temperature is consistently maintained at –10 °C, with continuous monitoring by the data logger. The external TEC also plays a role in maintaining a stable ambient temperature for other components of the spectrometer.

> **NOTE:**
> Temperature stability is crucial for preserving the accuracy and consistency of wavelength and irradiance intensity calibrations.
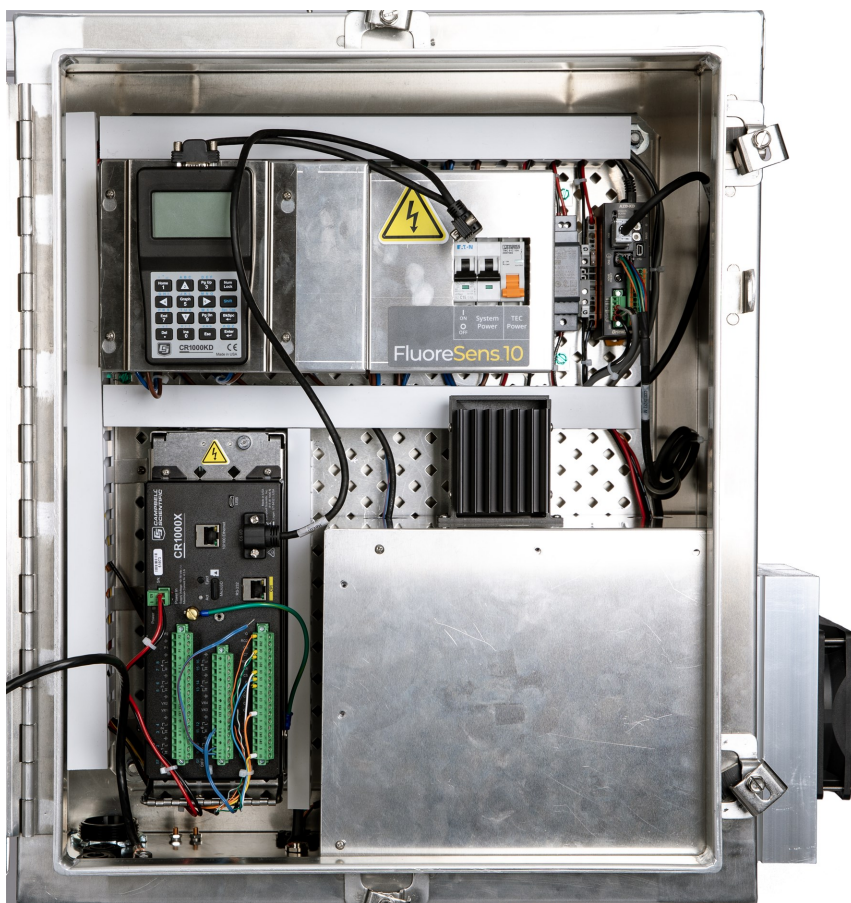
Figure 4-6. FluoreSens 10 with spectrometer enclosure cover on

4.1.5 Fiber optic cable guide

The wire guide includes a motor and an encoder, which together enable a 180-degree rotation. This rotation allows the wire guide to point upward toward the sky and downward toward vegetation, capturing radiation signals from each direction.

4.1.6 Optical fiber with cosine corrector

The radiation signals from both the sky and vegetation are transmitted through a fiber optic cable to the QE Pro. One end of the fiber optic cable is connected to a cosine corrector (CC-3, OceanOptics Inc., Dunedin, FL, USA), while the other end is connected to the SMA connector of the spectrometer (see Figure 4-2 [p. 5]). The cosine corrector is used to increase the field of view and collect light from a 180° angle. The fore optic section of the instrument with the cosine corrector is controlled by a motor to move between sky (pointing directly upward) and vegetation (pointing directly downward) positions.

5. Specifications

5.1 QE Pro

Table 5-1: Spectral characteristics of QE Pro (Ocean Insight spectrometer) in FluoreSens 10		
Optical parameter	Value	Description
Spectral range	650 to 800 nm	Cover O_2A and O_2B band
Spectral resolution	0.3 nm	Full Width at half Maximum (FWHM)
Spectral sampling interval	0.17 nm	1024 pixels
Signal-to-noise ratio (SNR)	1000:1	
A/D resolution	18 bits	200,000 digital counts
Field of view	180 degrees	
Grating (grooves/mm)	H6	
Quantum efficiency (peak) (%)	90	
Entrance slit size	10 μm	

5.2 Flame

FLAME Spectrometer spectral range: 350 to 1000 nm

FLAME spectral resolution: 1.3 nm

Grating   #3

Entrance Slit   25 μm

Pixels: 1–5   Not usable

Pixels: 6–18   Optical black pixels

Pixels: 19–21   Transition pixels

Pixels: 22–3669   Optical active pixels

Pixels: 3670–3681   Not usable

5.3 Power and temperature specifications

The system uses an AC power supply branched out into 4 power supplies with the following specifications:

- Motor controller and motor power supply: A 24V 10A power supply is required for the motor controller and motor.

- TEC/TEC controller power supply: A 12V 10A power supply is needed for the TEC and TEC controller.

- Charger supply: The 12V charger supply provides power to the data logger and charges the 12V 7Ah battery.

- 5V supply: The 5V supply powers the QE Pro spectrometer and optional Flame spectrometer.

Total power consumption: 130 W at 25 °C to 150 W at 50 °C

Operating temperature range: 0 to 50 °C

5.4 System enclosure weight and dimensions

Weight: ~50 lbs

Dimensions: 24 in × 20 in × 10 in (60.96 cm × 50.8 cm × 25.4 cm)

6. Installation

*Figure 6-1. FluoreSens 10 system mounted on a tripod
(tripod and cross-arms are sold separately)*

The following tools are required to install a FluoreSens 10 system in the field. Additional tools may be required for a user-supplied tripod or tower.

- 9/16-in open end wrench
- 1/2-in open end wrench
- 9/64-in hex key
- Adjustable wrench
- Sledgehammer (to drive grounding rod into the ground)
- Small, flat-tip screwdriver
- Large, flat-tip screwdriver
- Zip ties

6.1 Mounting and wiring

6.1.1 FluoreSens 10 enclosure

While the temperature inside the enclosure is regulated by the TEC, it is strongly advised that the enclosure be installed in a shaded area. Even though the TEC helps to control the internal temperature, external factors such as direct sunlight can still impact overall thermal conditions. By placing the enclosure under a shade, one can further enhance the stability of the internal temperature and ensure optimal performance of the system.

Enclosures for SIF systems can be configured with one of several mounting options offered by Campbell Scientific.

The following mounting options are available:

- Tripod mast 3.8 to 4.8 cm (1.5 to 1.9 in) diameter
- Tripod leg (CM106B)
- Cross arm (CM206)

> **DANGER:**
> To prevent accidents, injuries, or damage to the spectrometer, it is advisable that a second person is involved when lifting, moving, or installing the enclosure.

6.1.2 Fiber guide/motor controller
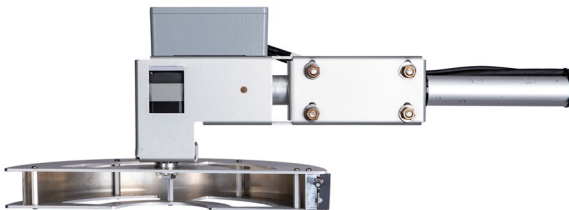

Figure 6-2. Top view of fiber guide. Two U-bolts are used to attach the fiber guide to a cross-arm

The fiber guide assembly should be mounted on a crossarm such that its field of view is unobstructed.

Mount the fiber guide/motor bracket to the end of horizontal pole. The pole goes below the bracket and is secured with U-bolts. The pole should be parallel with the ground. The guide

assembly will hang below the bracket, as shown in Figure 6-2 (p. 12). **Do NOT attach fiber cables at this stage.**

> **NOTE:**
> When fiber optic cable is attached to fiber guide in later steps below, allow enough slack in the cable to avoid tightness in the cable when the guide assembly rotates facing up and down.

6.1.3 FluoreSens 10 power, motor, and fiber optic cable

Follow the steps below to power the system with main AC power, connect the fiber guide assembly (power and motor cables) to the enclosure, and connect the fiber optic cable(s).

1. Loosen the nut on the cable gland on the bottom of the enclosure that is in line with the QE Pro spectrometer. Feed the fiber optic cable through the cable gland and connect the fiber optic cable to the QE Pro (and Flame). Connect the cosine corrector to the other end of the fiber optic cable.

   > **NOTE:**
   > The QE Pro and Flame have separate, individual fiber optic cables. The fore optic ends (with the cosine corrector) of the fiber optic cable(s) are clamped onto the fiber guide. In the event that a spectrometer needs to be removed from the temperature-controlled enclosure, remove the fiber optic cable first, followed by the power and communication connector. (See Removing and reconnecting spectrometer(s) [p. 38].)

2. Connect the motor power cable (thick cable) connector and encoder cable connector to the mating connectors on the bottom of the enclosure.

3. Power the system using AC main supply. Loosen the screw on the hinged stack bracket and lift the data logger to access the power terminal. Connect the AC power cable to power terminal located beneath the data logger.
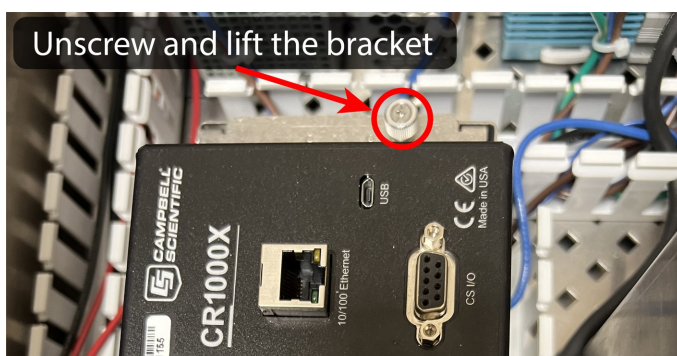
Figure 6-3. CR1000X data logger and Hinge Stack Bracket

> **DANGER:**
> To ensure safety and prevent the risk of electrocution or fatal accidents, it is highly recommended to have a licensed electrician handle the AC connection.

4. Turn the power and TEC switch **On** (see Figure 6-2 [p. 12]). Motor guide assembly will rotate to the "sky" position on program start. It may rotate one or two full rotations, due to handling. **To prevent fiber cable damage, do not attach the cable at this point.**

5. Pause the program by switching to **Pause** mode in *RTMC*. (Connect your laptop to the data logger with a USB cable or use a CR1000KD; see Absolute irradiance calibration and manual dark current measurement using RTMC [p. 20].) Wait until the cycle completes; this may take up to one minute depending on current integration time.

    If the system is set up inside the lab under low light conditions, connect the cosine corrector to the calibration lamp to provide sufficient light to the QE Pro spectrometer. In low light conditions, the measuring cycle may not complete, and the system may not switch to **Pause** mode.

6. Perform absolute irradiance calibration followed by dark current measurement for QE Pro (and Flame); (see Absolute irradiance calibration and manual dark current measurement using RTMC [p. 20]).

7. Mount the fore optic end of the fiber optic cable, with the help of a hex key, to the fiber guide. Do not overtighten the screw to avoid damaging the cable. Leave enough cable to loop around the fiber guide for both the sky and vegetation positions. Loosely secure the cable to the cross arm few feet (~2 ft) away from the guide using a zip tie, ensuring the cable stays within the walls of the fiber guide. Avoid leaving too much slack, especially on tall towers with windy conditions, as excess slack can cause the cable to slip out of the guide. Test the setup by changing the mode to **Pause** and manually rotating the guide by

switching between **Sky** and **Veg position** under the RTMC Fiber Position. Adjust the fiber guide's attaching point on the cross arm as needed, then tighten the zip ties just enough to secure the position (see Figure 6-1 [p. 11]).
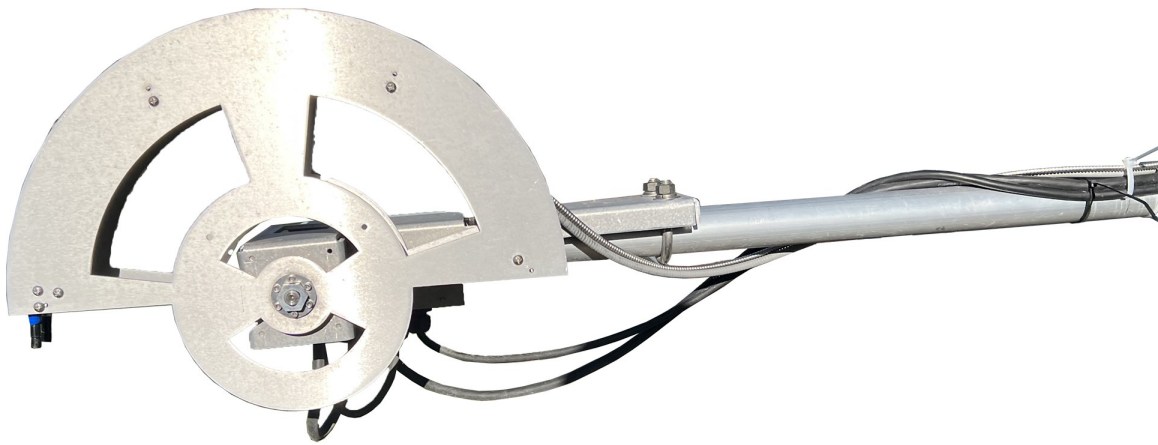
Figure 6-4. Fiber guide with fiber optic cables attached to a cross arm. The fiber optic cables are routed with a slight twist, or at an angle around the crossarm, instead of being tied strictly parallel to it. This slight angling allows the fibers to stay properly seated inside the guide, maintaining gentle pressure against the guide walls and preventing slippage during rotation.

8. Switch the **System Mode** to **Run/Sample** to start the measurement.

> **NOTE:**
> If the fiber guide is not correctly aligned to sky and vegetation positions, follow the steps in Repositioning fiber guide (p. 36).

6.1.4 Attach drip pan and insect screen

Place the drip pan below the TEC fan inside of the enclosure, insert the pipe from the bottom of enclosure and screw onto the drip pan, as shown in Figure 6-5 [p. 16]. Then, attach the screen onto the pipe. This setup will prevent moisture build up inside the enclosure.
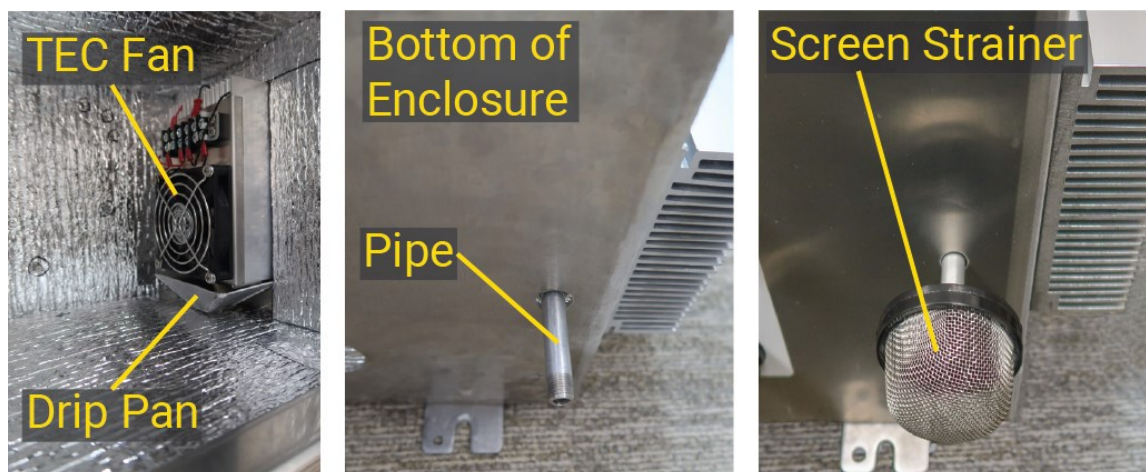
Figure 6-5. Moisture drip pan, pipe and insect screen

6.1.5 Instrument height

To ensure accurate SIF measurements, it's important to account for atmospheric effect due to aerosols and molecular scattering in the airspace between the canopy and the receptor for upwelling radiance, as this factor can impact SIF readings. To minimize this influence, it is advisable to maintain a short distance between the canopy and the fiber optic guide, preferably less than 10 meters.

If the distance between the canopy and the sensor is too large, corrections may need to be applied to compensate for any signal loss in SIF measurements, as detailed in the following resource: https://doi.org/10.3390/rs10101551 .

6.1.6 SN500SS wiring

The SN500SS is a four-component net radiometer that provides SDI-12 output. To connect this optional accessory to the data logger, follow the order shown in the table.

Table 6-1: Wire color, function, and data logger connection		
Wire color	Wire function	Data logger connection
White	SDI-12 signal	C3
Clear	Shield	G
Red	Power	12V
Black	Power ground	G

6.1.7 Grounding

It is essential to earth ground both the fiber guide assembly and the enclosure. Grounding wire comes with the purchase of the FluoreSens 10 and should connect the fiber guide assembly to the grounding lug located at the bottom of the FluoreSens 10main enclosure.

> **NOTE:**
> The grounding lug for the fiber guide assembly is located underneath the guide arm.

Another grounding wire (user provided or purchased separately from Campbell Scientific) should connect the enclosure lug to an earth ground via a grounding rod. Refer to the Grounds ⬈ section of the *CR1000X Online Manual* ⬈ for information on earth grounding and lightning protection.

7. Data logger program

The core of FluoreSens 10 is a versatile data logging program called IMACSS (Integrated Measurement And Control System for SIF), which acts as a device driver to regulate and execute all functions of the spectrometer. IMACSS is responsible for controlling the CCD operating temperature, managing the buffer size for spectral data transfer and storage, setting spectral integration times, opening and closing the internal shutter, starting or stopping spectral sampling, and checking the spectrometer status. It coordinates the measurements of spectral and environmental variables while strictly adhering to a schedule. IMACSS is equipped with error detection and management features to handle unexpected events, such as power outages or communication interruptions with the spectrometer. If an error occurs, IMACSS enters an error mode, sends a diagnostic message to the program interface, and tries to reestablish communication with the spectrometer and reset it. If successful, it exits the error mode and proceeds to the next task in line. This system ensures that all measurements are carried out systematically and that the data recorded is not corrupted by unexpected events, thus simplifying the automated data management and post processing.

> **NOTE:**
> The data logger program (IMACSS) is encrypted and subject to a license agreement, so will not be shared with customers due to the licensing agreement. Please see Licensed materials (p. 41) for further details.

8. Operation

8.1 Measurement

The measurement and operation of the wire guide and spectrometer are controlled by a CRBasic program in the CR1000X data logger using its serial communication port.

The FluoreSens 10 uses a specific QE Pro spectrometer that has a signal-to-noise ratio of 1,000:1 for one measurement period. The spectrometer has a long-pass filter with a wavelength cutoff of over 800 nm, a 10-µm slit, and an H6 grating, which produces a spectral range between 650 and 800 nm with a resolution of 0.3 nm at half maximum width. This spectral range is appropriate for measuring sun-induced chlorophyll fluorescence (SIF) at both the O_2B and O_2A bands. Additionally, the spectrometer has an internally installed shutter that can open and close within 11 ms, which is controlled by the data logger. To collect photons from targets, such as outgoing irradiance from vegetation and incoming solar irradiance, a fiber optic cable is used to direct the photons to the spectrometer. The fore optic with cosine corrector attached to fiber guide is rotated 180 degrees upwards and downwards to alternately observe the sky and vegetation.

The duration during which the spectrometer's CCDs is exposed to incoming photons, which is referred to as integration time, is controlled by IMACSS. This integration time needs to be continuously adjusted to match the varying intensity of irradiance, optimizing the sensitivity of the spectrometer. Since measurements are taken alternately for outgoing and incoming irradiances, the integration time must also alternate, with longer durations for outgoing irradiance compared to incoming irradiance. Refer to Gu et al. (2019) for more details on integration time.

8.2 Field of view

The fore optics in FluoreSens 10 is a cosine corrector that has a field of view of 180 degrees. The use of cosine corrector instead of bare fiber for sampling outgoing irradiance from vegetation ensures good overlap of SIF and eddy covariance (EC) flux footprint. About 90% of the total radiation received by a cosine corrector will represent approximately 75% of the source area of flux measurements.

Combining SIF and EC data provides deeper understanding of ecosystem carbon and water cycles and can enhance the accuracy of gross primary productivity (GPP) estimates.

9. Calibration

Calibration of QE Pro and Flame spectrometers can be performed as described in the following sections.

Figure 9-1. HL-3P-CAL Radiometrically Calibrated Tungsten Halogen Light Source

9.1 Wavelength calibration

Spectrometers go out of calibration gradually over time. Its exposure to mechanical stress and temperature changes will accelerate this process. So, wavelength calibration once a year is recommended to correct for drift. Each spectrometer is shipped with a wavelength calibration data sheet that contains information unique to the spectrometer. In the post processing steps, the wavelength calibration coefficient in the calibration data sheet should be fitted to a third-order polynomial to calculate the wavelength associated to pixel counts. Refer to Ocean Insight website, www.oceaninsight.com/blog/spectrometer-wavelength-calibration ⬀, for more details.

9.2 Absolute irradiance calibration

To obtain accurate absolute irradiance measurements, a calibration process using a light source with a known power output is required. This involves measuring the spectrum with the sampling optic connected to the calibration light source and comparing it to the known output power of the calibration light source. QE Pro and the Flame spectrometer should be calibrated separately with the calibration light source. The resulting energy response data for each pixel in the CCD

(charged coupled device) can be used to determine the irradiance measurements in µW/cm^2/nm by taking into account the surface area of the sampling optic and the integration time.

> **NOTE:**
> While absolute irradiance calibration can be carried out in both field and laboratory settings, it is advisable to conduct it in a laboratory setting before the initial deployment of the FluoroSens 10 for convenience with the logistics.

9.2.1 Absolute irradiance calibration and manual dark current measurement using RTMC

Flame absolute irradiance calibration is generally not required, as vegetative indices are derived from the ratio of reflected to incident radiation, canceling out absolute values and making calibration unnecessary.

> **NOTE:**
> This functionality has been included for cases where quantifying changes in radiance flux, rather than relative reflectance, might be of interest to users. For example, PRI can be approximated using radiance-based calculations. Additionally, absolute calibration is useful when comparing data across different spectrometers or measurement setups.
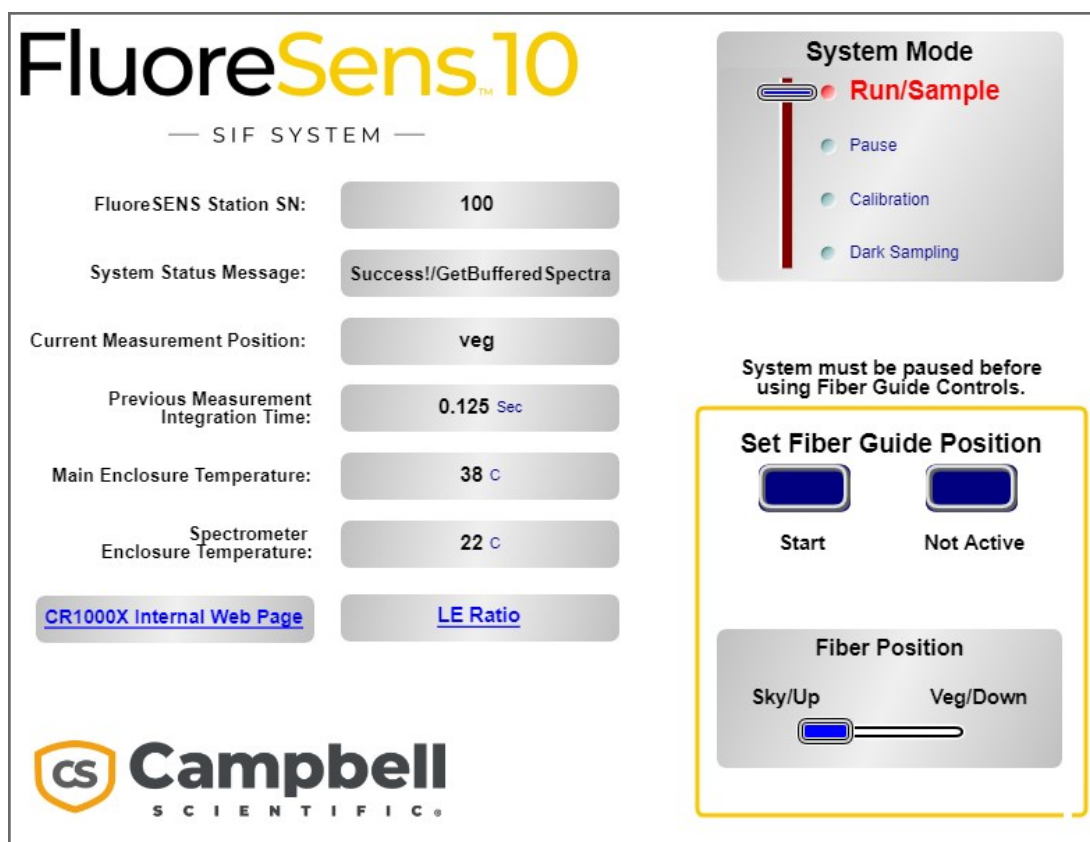
Figure 9-2. **Real-Time Monitoring and Control** *(RTMC) software panel to monitor and control FluoreSens 10 operations: (a) radiometric calibration, (b) manual dark sampling and (c) Real time monitoring of SIF signal*

The FluoreSens 10 **RTMC** panel displays useful data from the data logger. For example, the data loggers built-in web pages, which display data logger health and program statistics, such as panel temperature, battery voltage, and program run-time errors, can be accessed through **RTMC**.

The **RTMC** panel can also be used to perform absolute irradiance calibration with a lamp source and for manual dark sampling. The presence of the SIF signal in the data can be monitored by clicking on the **LE Ratio** panel, which will open a graph with apparent reflectance spectra plotted against pixel bins, demonstrating SIF excursions at the O_2A band and O_2B band in realtime.

To access the **RTMC** panel display, connect to a CR1000X over USB and type into a browser the data logger IP address for the USB port (192.168.66.1, by default, and 192.168.66.1/index.html for the **RTMC** display).

> **NOTE:**
> The absolute irradiance calibration and manual dark current sampling can also be performed using a CR1000KD.

> **NOTE:**
> *RTMC* can also be accessed remotely without a direct USB cable connection. Follow the steps in the *RTMC Pro* video (https://www.campbellsci.com/videos/rtmc-pro-software-publishing-data⬏) for a remote connection.

9.2.1.1 QE Pro calibration with lamp

The following steps should be followed for radiometric calibration/absolute irradiance using *RTMC*:

1. Connect the cosine corrector to the fore optic of fiber optic cable. Insert the cosine corrector into the port on the light source and tighten the set screw.

2. Connect power to the calibration lamp and allow 15 minutes for warmup.

3. Change **System Mode** to **Pause** to halt sampling operation. The system will first complete its measurement sequence, then **System Status Message** will change to **Pause**. At this point, remove the fore optic end of the fiber optic cable from fiber guide. Use a hex key to loosen the screw.

   > **NOTE:**
   > If absolute irradiance is being performed for the first time right after purchase of the system, removal of fiber optic cable from fiber guide will not be required.

4. Switch **System Mode** from **Pause** to **Calibration**. The **System Status Message** will change to **Connect Lamp**.

5. Switch the position from **Calibration** to **Sample** for the spectrometer to sample the lamp. If you mistakenly switch from **Calibration** to **Pause**, you will cancel the calibration, and the system will need to return to normal sampling first, even if it is already sampling a lamp and the motor is running.

6. The system will measure 50 samples and **System Status Message** will change to **CAL:Done-RemoveLamp**. The integration time for each sample is automatically determined by the program based on the intensity of light.

9.2.1.2 Flame calibration with lamp

1. Once QE Pro calibration is complete, if Flame spectrometer is connected and **FLAME_ OPTION** is enabled in **Compile_Options** then the program gets ready for Flame calibration. **System Status Message** will change to **QePro-Done/StartFlame**.

   System Mode may appear to be **Run/Sample** at the end of QE Pro Calibration.

2. Refresh the RTMC page so that correct **System Mode** of **Calibration** is displayed.

3. Remove QE Pro cosine corrector from the lamp and connect Flame fiber optic cosine corrector to the lamp.

4. Switch **System Mode** from **Calibration** to **Run/Sample** to start measuring lamp spectra.

5. The Flame will take 50 light spectra samples.

9.2.1.3 QE Pro and Flame manual dark sampling

1. Switch back to **Pause** mode, wait for **System Status Message** to change to **Put Cover Set Light Source Dark**.

2. Use the shutter on the lamp to block the light, or cover the fore optic for dark measurements. Switch to **Dark Sampling** mode, then to **Run/Sample** mode to take a manual dark sampling measurement. First, QE Pro will measure a total of 15 samples, with each of the three integration times (**0.01s**, **25.01s**, and **50.01s**) being replicated 5 times. These QE Pro dark samples are saved in **SpectralTable** and **LightSource** is labeled as '**Dark-C**'.

3. After completion, if Flame is attached to the system, Flame spectrometer will make 15 samples with integration times of **0.004s**, **4.5s**, and **9s**. These Flame dark samples will be saved in **FlameSky** table and labeled as '**Dark-C**' in **LightSource** field.

4. After the measurement is completed, remove the cover and attach the fiber optic cable(s) to fiber guide clamp. Switch the **System Mode** to **Run/Sample**to start sky and veg measurements.

> **NOTE:**
> If Flame is not connected, then remove the cover and switch back to **Pause** mode, connect the fiber optic cable to fiber guide clamp, and then switch to **Run/Sample** mode to start the measurements.
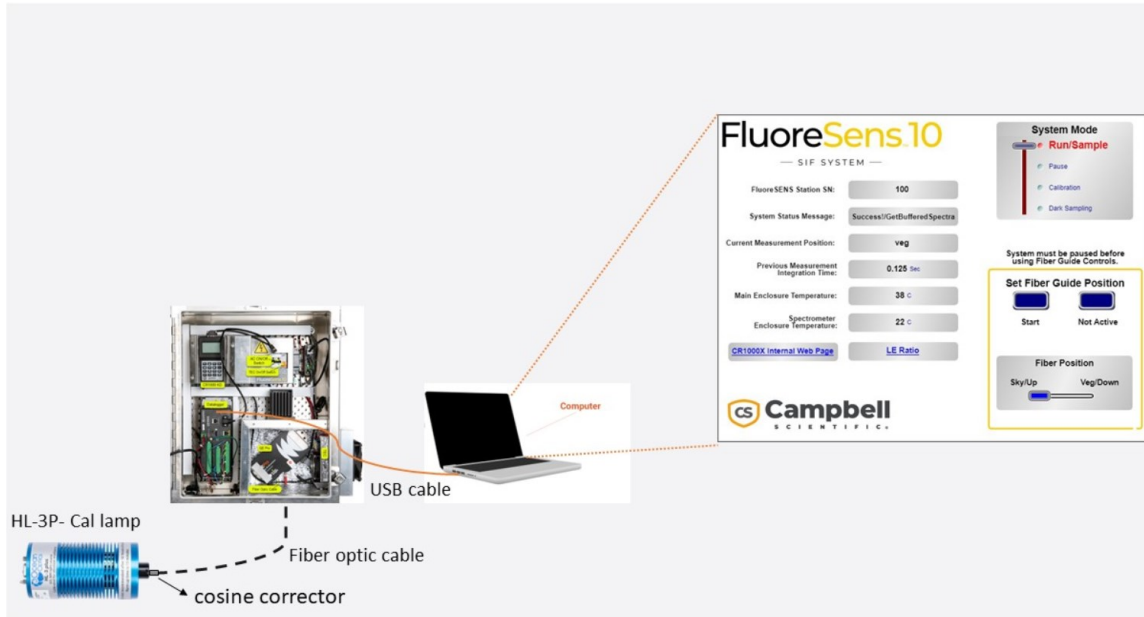
Figure 9-3. Absolute irradiance calibration set up

> **NOTE:**
> While QE Pro dark measurements are being recorded, no Flame dark measurements are recorded in **FlameSky** or **FlameVeg** tables. The same is true for Flame, that is, during Flame dark measurements, no QE Pro dark measurements are saved in **SpectralTable**.

> **NOTE:**
> If Flame is not purchased with FluoreSens 10 system, the **FLAME_OPTIONS** in **CompleOptions** is set '**false**' by default, so only QE Pro manual dark measurements will be made by the system.

9.2.2 Absolute irradiance calibration and off-sequence dark sampling using a CR1000KD

Connect a **CR1000KD** to the **CSI/O** port of the CR1000X data logger. Press Enter twice to reach the main menu. Within the main menu, utilize the keypad's downward arrow to navigate through

the various submenus and options. Select your preferred option and press **Enter**. If you need to go back to a previous menu, press **Esc**.

Follow the steps below using a CR1000KD to perform calibration and dark sampling in the field under a clear sky with adequate sunlight. The system requires sufficient light to complete a measurement cycle before the **System Mode** can be switched to **Pause**:

1. Change **Operating Mode** to **Pause** to halt sampling operation. The system will first complete its measurement sequence. **SystemStatus** under **Status** should change to **Pause**.

2. Remove the fore optic end of the fiber optic cable from fiber guide. Use a hex key to loosen the screw.

3. Switch **Operating Mode** from **Pause** to **SIF_CALIBRATE**. The **System Status** Message should change to **Connect Lamp**.

4. Connect power to the calibration lamp and allow 15 minutes for warmup. (The lamp can be powered on before step 1 to save time.)

5. Connect the fore optic to the calibration lamp and tighten the set screw.

6. Switch the position from **SIF_CALIBRATE** to **RUN_SAMPLE** to sample the lamp. The number of measured samples can be tracked under **Status >>SystemStatus**.

7. This process will result in 50 lamp irradiance measurements. Next perform manual dark measurements.

> **NOTE:**
> If calibration is performed in the lab under low light conditions, first **turn off the system and detach the fiber optic cable(s) from the fiber guide**. Then, follow the steps above in the following sequence: **4, 5, 1, 3, 6, and 7**.

> **NOTE:**
> Similar to QE Pro, Flame lamp measurement can also be made using CR1000KD and switching between the modes.

> **NOTE:**
> It is important to note that for an absolute irradiance calibration to be considered valid, all hardware elements comprising the measurement system must remain unchanged. This includes the fore optic (such as a cosine corrector or bare fiber), the fiber, and the spectrometer. It is important to note that no two spectrometers are identical. Consequently, any modification or alteration to any component of the system necessitates a new absolute irradiance calibration.

9.2.2.1 Manual dark sampling using a CR1000 KD

1. Switch **Operating Mode** from **SIF_CALIBRATE** to **Pause** (wait for the **SystemStatus** to change to **Pause** and then switch to **DARK_SAMPLE**. The **SystemStatus** Message should change to **Put Cover Set Light Source Dark**.

2. Use the shutter in the lamp to block the light or cover the fore optic. Switch to **RUN_SAMPLE** to take a manual dark sampling measurement(s). After 15 samples are taken, the **SystemStatus** message will change to **Remove Cover**.

   > **NOTE:**
   > Flame will also measure 15 dark measurements if Flame is connected to the system.

3. Remove the cover and switch back to **Pause**.

4. Attach the fiber optic cable(s) to the fiber guide then switch **Operating Model** to **Run_Sample** to start vegetation and sky irradiance measurements.

10. Sequence of measurement

10.1 Sky and vegetation irradiance measurement

As soon as the system is turned on, the fiber guide will come to home position (that is, fore optics will point to the "sky" position). The following sequence will be used by the IMACSS code for a full set of measurements required for a single SIF retrieval.

1. Sky position integration time is estimated for incoming irradiance sampling.

2. If the desired CCD target count is not within an acceptable range, return to Step 1.

3. Position the fiber optic downward for outgoing irradiance sampling.

4. Estimate the integration time for outgoing irradiance sampling.

5. If the desired CCD target count is outside an acceptable range, return to Step 4.

6. Position the fiber optic upward for the next incoming irradiance sampling.

10.2 In-sequence dark current measurement

The charged couple device (CCD) in the spectrometers generates counts even in total darkness, leading to dark currents that require correction. These dark currents consist of readout and thermal noise, and dark measurements are taken outside the full irradiance sampling sequence.

The IMACSS in the current version measures QE Pro dark current at night (10 PM to 12 PM) at various integration times (such as 0.01 sec, 25.01 sec, and 50.01 sec) to allow modeling of the pixel dark count as a function of integration time (see Dark current correction [p. 28]). The program will continue to run for the remaining period of the nighttime but no spectral measurements will be saved to data table. This is because the integration time will exceed the program's current limit, which is set at 1 minute. Therefore, the optimization algorithm will continually attempt to find an acceptable optimal integration time until it succeeds, i.e., after sunrise.

> **NOTE:**
> IMACCS does not perform Flame in-sequence dark current measurement due to absence of built-in mechanical shutter in Flame spectrometers.

11. Data retrieval

The CR1000X data logger has limited internal data storage capacity; therefore, a microSD flash card is provided for expanded local storage. In addition to local storage, time series data can be transferred or streamed remotely using telemetry or network communication options. For more information on data storage and remote data transfer solutions, please contact Campbell Scientific.

> **NOTE:**
> The microSD flash cards from various manufacturers may have slightly different memory sizes on their 2 GB, 8 GB, and 16 GB cards, respectively. Also, as a card ages, some of its sectors may become unusable, decreasing the available memory.

> **NOTE:**
> For more information on data logger security and data collection, please refer to the online CR1000X manual ↗.

> **WARNING:**
> Campbell Scientific recommends and supports only the use of microSD cards obtained from Campbell Scientific. These cards are industrial grade and have passed Campbell Scientific hardware quality testing. Use of consumer grade cards substantially increases the risk of data loss.

12. Post processing

The data post processing comprises the following steps:

1. Wavelength calculation

    The wavelength associated with each pixel number in the QE Pro and Flame spectrometers are determined using a polynomial relationship between the pixel count of the spectrometer reading and the corresponding actual wavelength:

    $$\lambda_p = \lambda_0 + C_1 p + C_2 p^2 + C_3 p^3$$ Eq. 1

    Where λ_p is the wavelength of pixel number p; λ_0 is the wavelength of the first pixel; and C_1, C_2, and C_3 are coefficients.

    The QE Pro spectrometer consists of a total of 1044 pixels. The first 4 pixels and last 4 pixels are dummy pixels that are intentionally blocked. The 6 pixels that follow the first four dummy pixels and 6 pixels before the last four are optically dark pixels. Generally, only 1024 pixel in between these pixels are used for SIF analysis.

    > **NOTE:**
    > All coefficients can be found on the calibration sheet that is provided.

2. Dark current correction

    Linear regression is used to correct for dark current in CCDs by analyzing the relationship between the dark count (D) and the integration time (t_{int}) for each active pixel (wavelength, λ):

    $$D(\lambda) = D_0(\lambda) + D_1(\lambda) t_{int}$$ Eq. 2

    In the above equation, D_0 represents the noise during readout, while D_1 represents the coefficient that captures the thermal response to integration time. Both D_0 and D_1 are calculated for each pixel by performing a regression analysis on measurements taken during nighttime with the shutter closed or when performing a manual dark current sampling task. (For more information on manual dark current sampling, see Absolute irradiance calibration and manual dark current measurement using RTMC [p. 20].) These determined values are then used to correct the spectral measurements.

3. Nonlinearity correction

Nonlinearity in a spectrometer refers to the problem in which the spectrometer response to radiance is not linear across its entire dynamic range (in this case, from 0 to 200,000 for QE Pro). The sensitivity of the detector is determined by the change in pixel count (S) observed due to a change in the signal at the detector. The nonlinearity-corrected counts are calculated as:

$$L = D + \frac{S - D}{C_0 + C_1(S - D)^1 + C_2(S - D)^2 + \ldots + C_7(S - D)^7}$$

Eq. 3

Here, L is the nonlinearity-corrected count; S is the raw count; D is the dark count; and C_0, C_1,..., and C_7 are empirical coefficients available in the calibration data sheet provided by the manufacturer and assumed identical for all pixels.

4. Absolute irradiance conversion

Convert raw counts of CCD to absolute irradiance using pixel counts measured using a calibration lamp and lamp coefficients (an *.lmp* file is provided by the manufacturer, or the coefficients can be found in the lamp calibration data sheet).

The pixel-specific count to irradiance conversion factor, b(λ), is determined as:

$$b(\lambda) = \frac{\overline{L_L(\lambda) - D(\lambda)}}{t_{int}. E_L(\lambda)}$$

Eq. 4

Where L_L is nonlinearity-corrected counts measured on the calibration lamp; E_L ($\mu W\ m^{-2}$ nm^{-1}) is the known irradiance of this lamp; t_{int} is the integration time in seconds; and b is the conversion coefficient in the unit of counts m^2 nm μJ^{-1}.

The pixel counts to irradiance value (L(λ), downwelling and upwelling radiation) is converted by the following equation:

$$E(\lambda) = \frac{\overline{L(\lambda) - D(\lambda)}}{t_{int}. b(\lambda)}$$

Eq. 5

5. SIF retrieval

The retrieval of sun-induced chlorophyll fluorescence (SIF) is performed.

NOTE:
Recommendations for frequency of calibrations:

1. Wavelength calibration: We recommend an annual servicing of your spectrometer wavelength calibration for optimal performance. Over time, the calibration gradually drifts, and external factors such as vibration, temperature changes, and physical impacts can expedite this process. You have the option to send it to the manufacturer for calibration service, or you can perform the calibration yourself using an appropriate wavelength calibration source (HG-2 Mercury-Argon Wavelength Calibration lamp) with a 50 micron diameter fiber. However, professional calibration utilizes multiple light sources for calibration, resulting in greater accuracy and better calibration quality with more peaks used.

2. Calibration frequency for lamp HL-3P-Cal: After using the HL-3P-CAL lamp for either a year or 50 hours, whichever comes first, calibration is recommended. This duration includes warmup time. Keeping a log of the hours used can help you track when the calibration is due.

3. Absolute irradiance calibration: If your spectrometer is calibrated for absolute irradiance using a fiber and cosine corrector, the calibration remains valid for one year as long as the fiber remains connected. The integrating sphere (cosine corrector) can be removed and placed back on with the calibration remaining valid. However, it would need to be the same model of integrating sphere.

13. SIF retrieval

Retrieving sun-induced chlorophyll fluorescence (SIF) is still an area of ongoing research. Various methods have been explored to separate the SIF signal from incoming and reflected solar radiation. The two most common methods for SIF retrieval are:

1. Fraunhofer line depth method: This approach involves achieving high spectral resolution to effectively resolve individual Fraunhofer lines, allowing for the assumption of constant reflectance and SIF on either side of a Fraunhofer line.

2. Spectral Fitting Method: This method involves using low order polynomial functions (SFM, spectral fitting method) to represent the spectral variations in reflectance and SIF.

14. Output tables

14.1 Spectral table

The Spectral table records both sky and vegetation measurements from QE Pro.

Table 14-1: Spectral table		
Parameter	Description	Unit
Timestamp	Date and time	datetime
Record	Record number	
MotorFiberFace_Trk	Direction fiber cable is pointing for measurement — veg or sky	
nEvent	Number for measurement	
mSecSinceTrig_QEPro	Timer starts up on request for spectrum data from QE Pro, which determines the elapsed time required to get the spectrum measurement	milliseconds
IMACSSCode	0 — incoming irradiance measurement (sky) 1— outgoing radiance measurement (vegetation) 7 — dark current measurement at night	
CurrentIntegTimeInuSec	Integration time for the measurement	seconds
LightSource	nature = 'sky' or 'veg' Dark-C = manual dark current during calibration Dark-N = In-sequence dark current at night time	
CurrentSpecPixelCounts	Pixel counts 1–4: dummy pixels (not usable) 11–1034: active usable pixels 1041–1044: dummy pixels (not usable) (Dummy pixels located at the edges of the detector are not optically active, although they can be used for electronic dark correction in case dark current measurements are missing.)	counts per nm

14.2 FlameVeg data table and FlameSky data table

The **FlameVeg** table records vegetation measurements and the **FlameSky** table records sky measurements. These tables will be displayed in LoggerNet only if **FLAME_OPTION** under **CompileOptions** is set as **True** and will have data only if Flame is connected.

Table 14-2: FlameVeg, and FlameSky data tables		
Parameter	Description	Units
TIMESTAMP	Time of measurement	datetime
RECORD	Number of data recorded	
nEvent	Number of data records that will restart every time the system boots up	
MotorFiberFace_Trk	Sky or veg	
LightSource	nature = 'sky' or 'veg' Dark-C = manual dark current during calibration Dark-N = In-sequence dark current at night time	
mSecSinceTrig_QEPro	Timer started when QE Pro was triggered to get a new spectrum	
mSecSinceTrig_Flame	Timer started when Flame spectrometer was triggered to get a new spectrum	Difference between this and mSecSinceTrig_QEPro is amount of time QE Pro measurement lags the Flame measurement
Spectrum_nBytes	Number of bytes of data received from Flame spectrometer	
SpectrumTimer_mSec	Amount of time needed to collect a spectrum from Flame spectrometer	milliseconds

Table 14-2: FlameVeg, and FlameSky data tables		
Parameter	Description	Units
FlameWait_Calc_mSec	Calculated wait time for new spectrum acquisition	milliseconds
FlamePixelTarget	Desired CCD count that helps determine integration time	
PixelMaxValue	Flame peak pixel count	
PixelMaxV_Bin	Flame pixel number corresponding to peak pixel count	
Integration_uSec	Actual Flame integration time	microseconds
SetFlameIntegrationSuccess	Flag indicating integration time sent by the program was successful	-1 = Success 0 = Failed
Pixel (22 -3669)	Optical active pixels	3648 active pixel

15. Set up and measurement workflow

Set up, calibration, initiation of measurements, and retrieval of SIF can be summarized in the following steps:

Mount the FluoreSens 10 enclosure on the tripod and the fiber guide on the crossarm Mounting and wiring (p. 12).

↓

Connect the motor encoder cable and motor power cable to the enclosure. See FluoreSens 10 enclosure (p. 12).

↓

Connect one end of fiber optic cable(s) to SMA connector of spectrometer(s). See Fiber guide/motor controller (p. 12).

↓

Perform Absolute Irradiance calibration(s) and dark measurement(s). See Absolute irradiance calibration (p. 19).

↓

Pause the system and connect the fiber cable(s) to the Fiber Guide assembly. See Absolute irradiance calibration (p. 19).

↓

Start making measurements and collect data.

↓

Perform SIF retrieval (p. 30) with SIF retrieval algorithms and estimate Vegetation indices (p. 35).

16. Vegetation indices

The pixel counts from a Flame spectrometer that are associated to reflected radiation values at specific wavelengths are used to calculate vegetation indices: **NDVI**, **EVI** and **PRI**.

For converting the pixel counts to radiation values, follow the steps described in

The Normalized Difference Vegetation Index (**NDVI**) is a measure of canopy greenness.

$$NDVI = \frac{\rho_{860} - \rho_{655}}{\rho_{860} + \rho_{655}}$$

Eq. 6

The Enhanced Vegetation Index (EVI) improves the assessment of green vegetation by compensating for structural and atmospheric influences. This is achieved through the adjustment of spectral regions with varying weights and the inclusion of an extra blue wavelength band in the calculation.

$$EVI = \frac{\rho_{758} - \rho_{670}}{\rho_{758} + 6\rho_{670} - 7.5\rho_{470} + 1}$$

Eq. 7

The Photochemical Reflectance Index (**PRI**) is a vegetation index that provides insights into the physiological state of plants, particularly their photosynthetic activity. It is primarily used as an indicator of water stress and for the assessment of carbon-dioxide uptake by plants.

$$PRI = \frac{\rho_{531} - \rho_{570}}{\rho_{531} + \rho_{570}}$$

Eq. 8

Other vegetation indices can also be calculated as needed from combinations of surface reflectance between 350 and 1000 nm.

17. Troubleshooting and maintenance

17.1 Repositioning fiber guide

The fiber optic guide may sometimes not accurately align with the sky or vegetation position due to various factors, including handling during shipping, interactions with birds, and tower installation on uneven ground. In such scenarios, the fiber guide should be accurately positioned using *RTMC*/CR1000KD and the home preset button in the AZD-KD (see FluoreSens 10 enclosure [p. 5] for more details).

1. Bring the **System Mode** to **Pause**. Wait for the current sampling to complete and **System Status Message** to change to **Paused: SetRunToStart**.

2. Press **Start** on the **Set Fiber Guide Position** panel located in the lower right on the *RTMC* panel. At this point, the motor is disengaged.

3. Level the fiber guide to the appropriate position. Hold the position and press **Engage Motor**.

4. On the AZD-KD, press and hold **Home Preset** for about one second until the red light starts blinking. Release the button and press it once more immediately to set the location of the fiber guide into the motor encoder memory. The LED will return to a steady green color.

5. Press **Position Set** again, then press **Exit/Cancel** to exit from fiber guide position mode.

6. Switch back to **Run/Sample System Mode** on the upper part of the *RTMC* panel to begin sampling/measuring again.

17.2 Repositioning the fiber guide using a CR1000KD

The fiber guide position can also be reset using a CR1000KD. Connect a CR1000KD to the **CSI/O** port of the CR1000X data logger, press **Enter** twice to access the main menu. Under the main menu, use the keypad down arrow to scroll down to each of the submenus. To select a submenu, highlight the desired submenu and press **Enter**. To return to the previous menu, press **Esc**.

Follow the steps below for fiber guide reorientation:

1. In the main menu: Select **Operation mode >> Pause**.

   (**SystemStatus** under Status menu will change to **'Paused'**).

2. Go to Motor/**Fiber Position**:

   - Change **Start Positioning** to **'True'** (Motor will be disengaged, **SystemStatus** will display **Motor Disengaged: Position Fiber Guide**)

   - Orient or level the fiber guide to the appropriate position then set **Hold: 'True'** (this will engage the motor)

3. On the AZD-KD, press and hold **Home Preset** for about one second until the red light starts blinking. Release the button and press it once more immediately to set the location of the fiber guide into the encoder memory. The LED will return to a steady green color.

4. **Motor/Fiber Position >> start-positioning >> False**.

5. **Operation mode >> RUN_SAMPLE** (the system will start spectra measurement again).

17.3 Flame and SN500 tables with no output

If Flame and SN500 table outputs are not updating, or meaningful values are not reported even if both sensors are connected, make sure **FLAME_OPTION** and **SN500_ENABLE** in the **CompileOptions** table are set to *true* (insert '1') and restart the program by setting **ApplyAndRestart** to *true* ('1') . The program will restart and both Flame and SN500 output will display under the **FlameSky**, **FlameVeg**, and **SN500** tables.

17.4 Error messages

Error messages could be related to the motor encoder, power loss, or communications issues. Most of the error codes are automatically cleared by the data logger code. Below is a list of errors that can be cleared and a list of errors that cannot be reset by the data logger program.

1. Loss of AC Power will trigger a motor error which will be reset by the program.

2. Communication errors between the QE Pro and the Logger can cause an error condition. The system will reset the QE Pro error. The system will stay in a pause/retry state until communication is restored to the QE Pro.

Some Motor Controller error codes are not programmatically resettable; they will need a power reset. Some motor error codes may indicate motor damage, which will require repair or replacement of the motor. The motor errors that cannot be reset by the data logger program are:

Const Mtr_Err 20h = 32 Over Current

Const Mtr_Err 28h = 40 Sensor Error - check motor connection /pwr cycle

Const Mtr_Err 2Ah = 42 ABZO Sensor communication error - check Encoder Cbl /pwr cycle

Const Mtr_Err 33h = 51 Absolute Position Error - reprogram Preset or Home operation

Const Mtr_Err 41h = 65 EEPROM Error - reinitialize all parameters

Const Mtr_Err 42h = 66 sensor Error at power on - ck ABZO sensor/pwr cycle

Const Mtr_Err 43h = 67 motor was rotating when pwr turned on

Const Mtr_Err 44h = 68 Encoder EEPROM error

Const Mtr_Err 45h = 69 Motor combination error

Const Mtr_Err 53h = 83 Emergency stop circuit error

Const Mtr_Err 71h = 113 Electric gear setting error

Const Mtr_Err 72h = 114 Wrap setting error

Const Mtr_Err 83h = 131 Comm switch setting error -Check BAUD switch

> **NOTE:**
> Motor errors are stored in the data loggers Public Table by the data logger program. The errors are in hexadecimal format and are displayed as a decimal number. Refer to the motor manual ⬈ for more detail on motor error messages.

17.5 Removing and reconnecting spectrometer(s)

Spectrometer(s) may need to be removed for replacement or storage during periods when measurements will not be made for an extended duration. Follow the steps below to ensure the safety of the fiber optic cable:

1. Carefully unscrew the SMA connector to disconnect the fiber optic cable.

2. Turn off the AC power supply and detach the 12V battery terminals to power down the spectrometer.

3. To create space for accessing the power and 30-pin connectors, remove the brackets securing the spectrometer.

4. Detach the power connector and disconnect the 30-pin connector (ribbon cable to the logger).

Follow the sequence below for reattaching the spectrometer(s):

1. Turn off the AC power supply and safely detach the 12V battery terminals to power down the system.
2. Place the spectrometer inside the enclosure, attach the power cable and 30-pin connector.
3. Carefully connect the fiber optic cable.
4. Once the fiber optic cable is securely connected, proceed to secure the brackets in place.

17.6 CardStatus error after setting SN500 in CompileOptions to true

If an SN500 is added to the FluoreSens 10 system at a later date, *CompileOptions* associated with this sensor will need to be set **true** to output the SN500 table. Following this step, you may encounter a '***Data on Cards is from a different program or is corrupted***' warning in **CardStatus** under the **Status** tab. This warning indicates that data is not being saved onto the card. The error occurs because a data table exists on the card that has the same name as one being output with the new program. This issue can be resolved by stopping the program, deleting all data tables in the microSD card, and starting the data logger program using **File Control** in the **Connect Screen**. Alternatively, the card can also be formatted after stopping the program. There are multiple methods available for card formatting, including options like File Control, CR1000KD, and Windows. It is advisable to perform the formatting on the data logger itself, as this guarantees the correct FAT32 format.

17.7 Enclosure desiccant

Check the humidity indicator card in the mesh pocket in the enclosure door. The humidity indicator card has three colored circles that indicate the percentage of humidity. Desiccant packets inside the enclosure should be replaced with fresh packets when the upper dot on the indicator begins to turn pink. The indicator card does not need to be replaced unless the colored circles overrun. Both desiccant packs and humidity cards can be purchased as replacements. See Replacement parts (p. 40) for more details.

17.8 TEC temperature in high humidity conditions

In tropical regions where temperature and humidity are high, setting the QEPro detector temperature higher may be necessary to prevent condensation, which can damage the electronics, especially during the rainy season. The default setting of -10°C may be too low under these conditions.

To minimize condensation, it is recommended to set the QEPro detector target temperature to 0°C or 10°C. This adjustment helps reduce condensation buildup and prolongs the detector's lifespan. This change needs to be made in data code IMACCS.

Contact Campbell Scientific for requesting the code change.

18. Support software

FluoreSens 10 comes preinstalled into the CR1000X that was purchased with this system.

18.1 *PC400*

PC400 is a user-friendly data logger support software that is available for free. It serves as an entry-level option and offers support for various telecommunication options, manual data collection, and data display. *PC400* includes several useful tools, such as an intuitive program generator called *Short Cut*, as well as comprehensive program editors like *CRBasic Editor*. These features enable users to easily create and edit programs for their data loggers.

18.2 *LoggerNet*

LoggerNet is a comprehensive software package designed to facilitate programming, communication, data collection, and display. It comprises a server application along with multiple client applications combined into a unified product. This software package is highly recommended for situations where telecommunication support, scheduled data retrieval, or large data logger networks are necessary.

19. Replacement parts

19.1 Silica desiccant bags

Silica desiccant bags (Figure 19-1 [p. 41]) are used to desiccate the system enclosure and should be periodically replaced. These can be purchased in packs of 1, 4, or 20.

Figure 19-1. Single desiccant pack

19.2 Humidity indicator card

The replacement humidity indicator card (Figure 19-2 [p. 41]) provides a visual reference of the humidity level inside the enclosure.

Figure 19-2. Humidity indicator card

20. Licensed materials

Statement of Licensed Materials

Some of the technologies employed by FluoreSens 10 are licensed materials. This technology acquired under license from UT-Battelle, LLC, the management and operating contractor of the Oak Ridge National Laboratory acting on behalf of the U.S. Department of Energy under Contract No. DE-AC05-00OR22725.(C) 2022 UT-Battelle, LLC. All rights reserved.

21. References

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Limited warranty

Covered equipment is warranted/guaranteed against defects in materials and workmanship under normal use and service for the period listed on your sales invoice or the product order information web page. The covered period begins on the date of shipment unless otherwise specified. For a repair to be covered under warranty, the following criteria must be met:

1. There must be a defect in materials or workmanship that affects form, fit, or function of the device.

2. The defect cannot be the result of misuse.

3. The defect must have occurred within a specified period of time; and

4. The determination must be made by a qualified technician at a Campbell Scientific Service Center/ repair facility.

The following is not covered:

1. Equipment which has been modified or altered in any way without the written permission of Campbell Scientific.

2. Batteries; and

3. Any equipment which has been subjected to misuse, neglect, acts of God or damage in transit.

Campbell Scientific regional offices handle repairs for customers within their territories. Please see the back page of the manual for a list of regional offices or visit www.campbellsci.com/contact ↗ to determine which Campbell Scientific office serves your country. For directions on how to return equipment, see Assistance.

Other manufacturer's products, that are resold by Campbell Scientific, are warranted only to the limits extended by the original manufacturer.

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Assistance

Products may not be returned without prior authorization. Please inform us before returning equipment and obtain a **return material authorization (RMA) number** whether the repair is under warranty/guarantee or not. See Limited warranty for information on covered equipment.

Campbell Scientific regional offices handle repairs for customers within their territories. Please see the back page of the manual for a list of regional offices or visit www.campbellsci.com/contact ↗ to determine which Campbell Scientific office serves your country.

When returning equipment, a RMA number must be clearly marked on the outside of the package. Please state the faults as clearly as possible. Quotations for repairs can be given on request.

It is the policy of Campbell Scientific to protect the health of its employees and provide a safe working environment. In support of this policy, when equipment is returned to Campbell Scientific, Logan, UT, USA, it is mandatory that a "Declaration of Hazardous Material and Decontamination" form be received before the return can be processed. If the form is not received within 5 working days of product receipt or is incomplete, the product will be returned to the customer at the customer's expense. For details on decontamination standards specific to your country, please reach out to your regional Campbell Scientific office.

> **NOTE:**
> All goods that cross trade boundaries may be subject to some form of fee (customs clearance, duties or import tax). Also, some regional offices require a purchase order upfront if a product is out of the warranty period. Please contact your regional Campbell Scientific office for details.

Safety

DANGER — MANY HAZARDS ARE ASSOCIATED WITH INSTALLING, USING, MAINTAINING, AND WORKING ON OR AROUND TRIPODS, TOWERS, AND ANY ATTACHMENTS TO TRIPODS AND TOWERS SUCH AS SENSORS, CROSSARMS, ENCLOSURES, ANTENNAS, ETC. FAILURE TO PROPERLY AND COMPLETELY ASSEMBLE, INSTALL, OPERATE, USE, AND MAINTAIN TRIPODS, TOWERS, AND ATTACHMENTS, AND FAILURE TO HEED WARNINGS, INCREASES THE RISK OF DEATH, ACCIDENT, SERIOUS INJURY, PROPERTY DAMAGE, AND PRODUCT FAILURE. TAKE ALL REASONABLE PRECAUTIONS TO AVOID THESE HAZARDS. CHECK WITH YOUR ORGANIZATION'S SAFETY COORDINATOR (OR POLICY) FOR PROCEDURES AND REQUIRED PROTECTIVE EQUIPMENT PRIOR TO PERFORMING ANY WORK.

Use tripods, towers, and attachments to tripods and towers only for purposes for which they are designed. Do not exceed design limits. Be familiar and comply with all instructions provided in product manuals. Manuals are available at www.campbellsci.com You are responsible for conformance with governing codes and regulations, including safety regulations, and the integrity and location of structures or land to which towers, tripods, and any attachments are attached. Installation sites should be evaluated and approved by a qualified engineer. If questions or concerns arise regarding installation, use, or maintenance of tripods, towers, attachments, or electrical connections, consult with a licensed and qualified engineer or electrician.

General
- Protect from over-voltage.
- Protect electrical equipment from water.
- Protect from electrostatic discharge (ESD).
- Protect from lightning.
- Prior to performing site or installation work, obtain required approvals and permits. Comply with all governing structure-height regulations, such as those of the FAA in the USA.
- Use only qualified personnel for installation, use, and maintenance of tripods and towers, and any attachments to tripods and towers. The use of licensed and qualified contractors is highly recommended.
- Read all applicable instructions carefully and understand procedures thoroughly before beginning work.
- Wear a hardhat and eye protection, and take other appropriate safety precautions while working on or around tripods and towers.
- 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.

Utility and Electrical
- 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.

Elevated Work and Weather
- 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.

Internal Battery
- 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.

Use and disposal of batteries
- Where batteries need to be transported to the installation site, ensure they are packed to prevent the battery terminals shorting which could cause a fire or explosion. Especially in the case of lithium batteries, ensure they are packed and transported in a way that complies with local shipping regulations and the safety requirements of the carriers involved.
- When installing the batteries follow the installation instructions very carefully. This is to avoid risk of damage to the equipment caused by installing the wrong type of battery or reverse connections.
- When disposing of used batteries, it is still important to avoid the risk of shorting. Do not dispose of the batteries in a fire as there is risk of explosion and leakage of harmful chemicals into the environment. Batteries should be disposed of at registered recycling facilities.

Avoiding unnecessary exposure to radio transmitter radiation
- Where the equipment includes a radio transmitter, precautions should be taken to avoid unnecessary exposure to radiation from the antenna. The degree of caution required varies with the power of the transmitter, but as a rule it is best to avoid getting closer to the antenna than 20 cm (8 inches) when the antenna is active. In particular keep your head away from the antenna. For higher power radios (in excess of 1 W ERP) turn the radio off when servicing the system, unless the antenna is installed away from the station, e.g. it is mounted above the system on an arm or pole.

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.

WHILE EVERY ATTEMPT IS MADE TO EMBODY THE HIGHEST DEGREE OF SAFETY IN ALL CAMPBELL SCIENTIFIC PRODUCTS, THE CUSTOMER ASSUMES ALL RISK FROM ANY INJURY RESULTING FROM IMPROPER INSTALLATION, USE, OR MAINTENANCE OF TRIPODS, TOWERS, OR ATTACHMENTS TO TRIPODS AND TOWERS SUCH AS SENSORS, CROSSARMS, ENCLOSURES, ANTENNAS, ETC.

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A worldwide network to help meet your needs

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