INSTRUMENTS

OWNER'S MANUAL

USB QUANTUM SENSOR

Model SQ-420

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DECLARATION OF CONFORMITY

CE and ROHS Certificate of Compliance

We Apogee Instruments, Inc.
721 W 1800 N
Logan, Utah 84321
USA

Declare under our sole responsibility that the product:

Model: SQ-420
Type: Quantum Sensor

are in conformity with the following standards and relevant EC directives:

Emissions: EN 61326-1:2013
Immunity: EN 61326-1:2013

EU directive 2004/108/EC, EMC
EU directive 2006/95/EC, Low Voltage Directive – Annex 1: Safety Objectives
EU directive 2002/95/EC, RoHS (Restriction of Hazardous Substances)
EU directive 2011/65/EU, RoHS2

Please be advised that based on the information available to us from our raw material suppliers, the products manufactured by us do not contain, as intentional additives, any of the restricted materials, including cadmium, hexavalent chromium, lead, mercury, polybrominated biphenyls (PBB), polybrominated diphenyls (PBDE).

Further note that Apogee Instruments does not specifically run any analysis on our raw materials or end products for the presence of these substances, but rely on the information provided to us by our material suppliers.

Bruce Bugbee, Ph.D.
President
Apogee Instruments, Inc.
February 2015

INTRODUCTION

Radiation that drives photosynthesis is called photosynthetically active radiation (PAR) and is typically defined as total radiation between 400 and 700 nm. PAR is often expressed as photosynthetic photon flux density (PPFD): photon flux in units of micromoles per square meter per second (μmol m^{-2} s^{-1}, equal to microEinsteins per square meter per second) summed from 400 to 700 nm (total number of photons from 400 to 700 nm). While Einsteins and micromoles are equal (one Einstein = one mole of photons), the Einstein is not an SI unit, so expressing PPFD as μmol m^{-2} s^{-1} is preferred.

The acronym PPF is also widely used and refers to the photosynthetic photon flux. The acronyms PPF and PPFD refer to the same parameter. The two terms have co-evolved because there is not a universal definition of the term "flux". Some physicists define flux as per unit area per unit time. Others define flux only as per unit time. We have used PPFD in this manual because we feel that it is better to be more complete and possibly redundant.

Sensors that measure PPFD are often called **quantum sensors**. A quantum is the minimum quantity of radiation (one photon), necessary to cause a physical, electrical, or chemical reaction (e.g., absorption by photosynthetic pigments). So one photon is a single quantum of radiation.

Apogee Instruments Quantum Sensor consists of a cast acrylic diffuser (filter), photodiode, and signal processing circuitry mounted in an anodized aluminum housing, and a cable to connect the sensor to a measurement device. The sensor is potted solid with no internal air space. It is designed for continuous PPFD measurement in indoor, outdoor and underwater environments. The SQ-420 sensor output increases linearly with PPFD under sunlight (natural setting) or electric lights (electric setting). The signal from the sensor is directly proportional to radiation incident on a flat surface where the radiation comes from all angles of a hemisphere.

SENSOR MODELS

This manual covers the USB quantum sensor model SQ-420. For unamplified models see manual for SQ-100 and SQ-300 sensors. For amplified models see manual for SQ-200 series quantum sensors.

Model	Signal	Calibration
SQ-420	**USB**	**Sunlight and Electric light**
SQ-110	Unamplified	Sunlight
SQ-120	Unamplified	Electric light
SQ-212	Amplified 0-2.5 V	Sunlight
SQ-222	Amplified 0-2.5 V	Electric light
SQ-214	Amplified 4-20 mA	Sunlight
SQ-224	Amplified 4-20 mA	Electric light
SQ-215	Amplified 0-5 V	Sunlight
SQ-225	Amplified 0-5 V	Electric light
*SQ-300 series are unamplified line quantum sensors		

Sensor model number, serial number, production date, and calibration factor are located near USB connector.

SPECIFICATIONS

Resolution: 0.1 μmol m^{-2} s^{-1}

Calibration Factor: custom for each sensor and stored in the firmware

Calibration Uncertainty: ± 5 % (see Calibration Traceability below)

Measurement Repeatability: less than 1 %

Non-stability (Long-term Drift): less than 2 % per year

Non-linearity: less than 1 % (up to 3000 μmol m^{-2} s^{-1})

Response Time: software updates every second

Field of View: 180°

Spectral Range: 410 nm to 655 nm (wavelengths where response is greater than 50 % of maximum; see Spectral Response below)

Directional (Cosine) Response: ± 5 % at 75° zenith angle (see Cosine Response below)

Temperature Response: 0.06 ± 0.06 % per C (see Temperature Response below)

Operating Environment: -40 to 70 C, 0 to 100 % relative humidity
Can be submerged in water up to depths of 30 m

Dimensions: 2.4 cm diameter and 2.8 cm height

Mass: Sensor head weighs 90 g

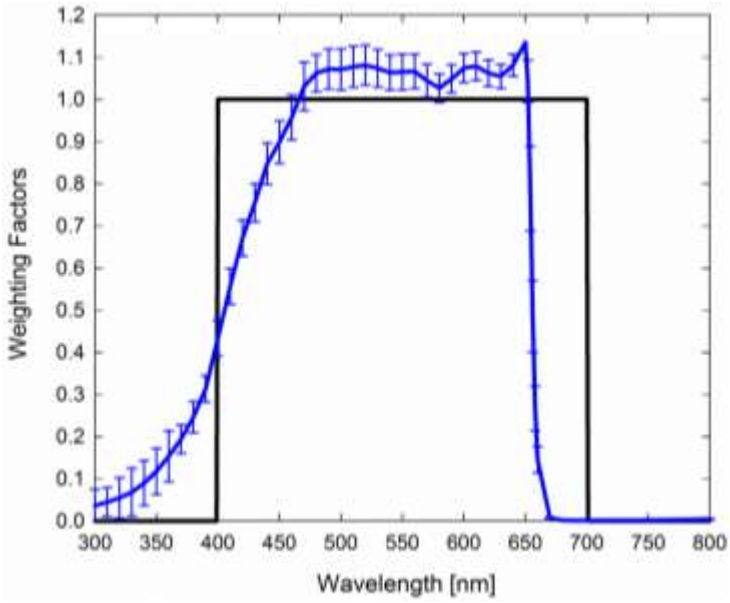
USB Cable: 4.6 m (15 ft)

Current Draw (when Logging): 0.35 mA

Calibration Traceability:

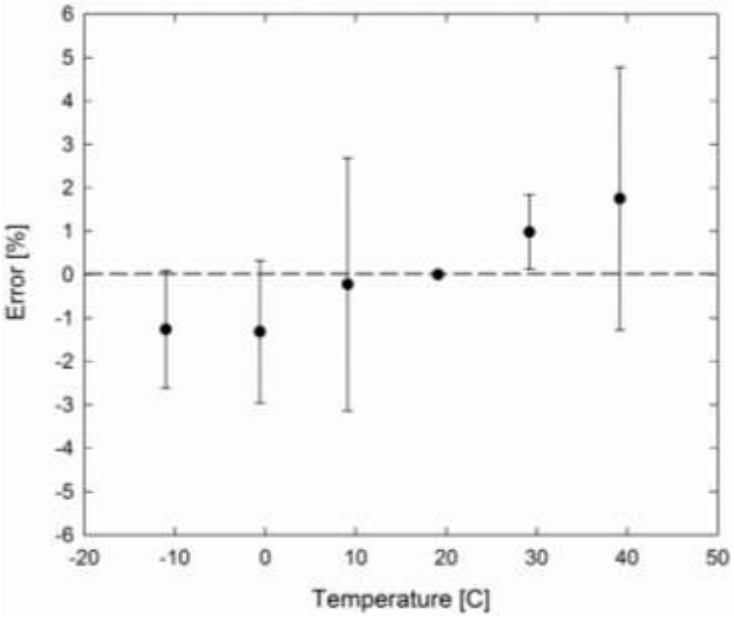
Apogee SQ series sensors are calibrated through side-by-side comparison to the mean of four Apogee model SQ-110 or SQ-120 transfer standard quantum sensors under high output T5 cool white fluorescent lamps. The transfer standard quantum sensors are calibrated through side-by-side comparison to the mean of at least three LI-COR model LI-190 reference quantum sensors under high output T5 cool white fluorescent lamps. The reference quantum sensors are recalibrated every 6 months with a LI-COR model 1800-02 Optical Radiation Calibrator using a 200 W quartz halogen lamp. The 1800-02 and quartz halogen lamp are traceable to the National Institute of Standards and Technology (NIST).

Spectral Response:



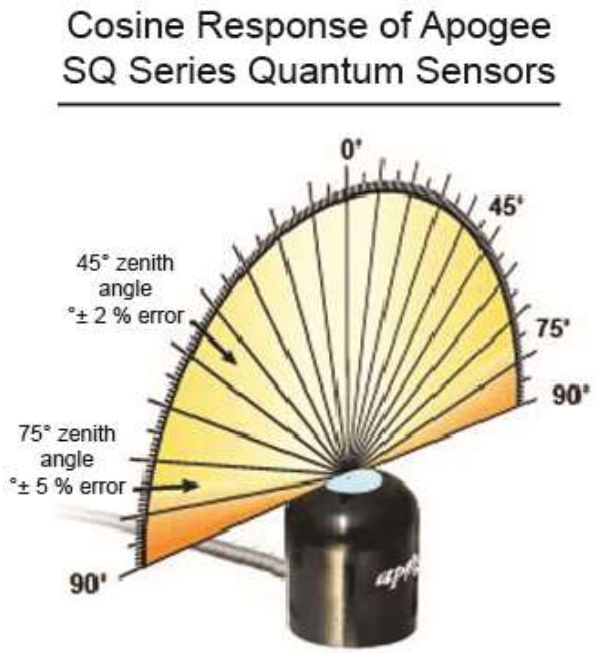
Mean spectral response of six sensors (***error bars represent two standard deviations above and below mean***) compared to PAR (PPFD) weighting function. Spectral response measurements were made at 10 nm increments across a wavelength range of 300 to 800 nm in a monochromator with an attached electric light source. Measured spectral data from each quantum sensor were normalized by the measured spectral response of the monochromator/electric light combination, which was measured with a spectroradiometer.

Temperature response:

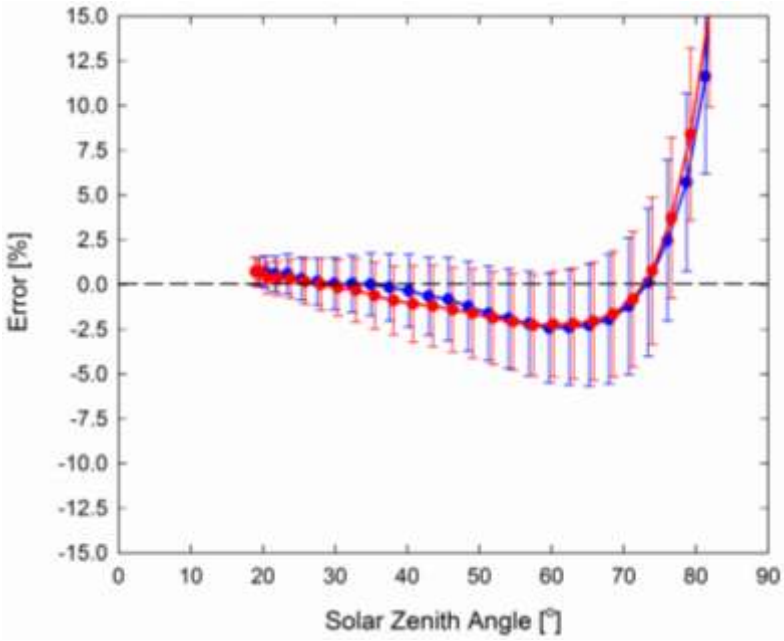


Mean temperature response of eight replicate sensors (***errors bars represent two standard deviations above and below mean***). Temperature response measurements were made at 10 C intervals across a temperature range of -10 to 40 C in a temperature controlled chamber under a fixed, broad spectrum, electric lamp. At each temperature set point, a spectroradiometer was used to measure light intensity from the lamp and all quantum sensors were compared to the spectroradiometer. The spectroradiometer was mounted external to the temperature control chamber and remained at room temperature during the measurements.

Cosine Response:



Directional, or cosine, response is defined as the measurement error at a specific angle of radiation incidence. Error for Apogee SQ series quantum sensors is approximately ± 2 % and ± 5 % at solar zenith angles of 45° and 75°, respectively.



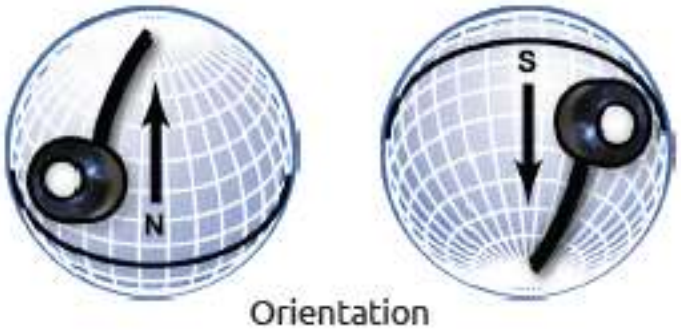
Mean cosine response of twenty-three replicate sensors (***error bars represent two standard deviations above and below mean***). Cosine response measurements were made by direct side-by-side comparison to the mean of four reference thermopile pyranometers, with solar zenith angle-dependent factors applied to convert total shortwave radiation to PPFD. Blue points represent the AM response and red points represent the PM response.

DEPLOYMENT AND INSTALLATION

Mount the sensor to a solid surface with the nylon mounting screw provided. To accurately measure PPFD incident on a horizontal surface, the sensor must be level. An Apogee Instruments model AL-100 leveling plate is recommended for this purpose. To facilitate mounting on a cross arm, an Apogee Instruments model AM-110 mounting bracket is recommended.

Model AL-100

To minimize azimuth error, the sensor should be mounted with the cable pointing toward true north in the northern hemisphere or true south in the southern hemisphere. Azimuth error is typically less than 1 %, but it is easy to minimize by proper cable orientation.



Orientation

In addition to orienting the cable to point toward the nearest pole, the sensor should also be mounted such that obstructions (e.g., weather station tripod/tower or other instrumentation) do not shade the sensor. **Once mounted, the green cap should be removed from the sensor.** The green cap can be used as a protective covering for the sensor when it is not in use.

Installing the software on a PC:

1. Double click on the installer package:
2. On the 'Welcome' screen, please click 'Next' to continue.
3. Select the radio button next to "I Agree" to the UELA… and click 'Next' to continue.
4. On the 'Ready to Install the Program' screen, click 'Install' to continue.
5. Click 'Finish' to complete the installation. There are shortcuts on your desktop and in your start bar.

OPERATION AND MEASUREMENT

Spectral Errors and Yield Photon Flux Measurements:

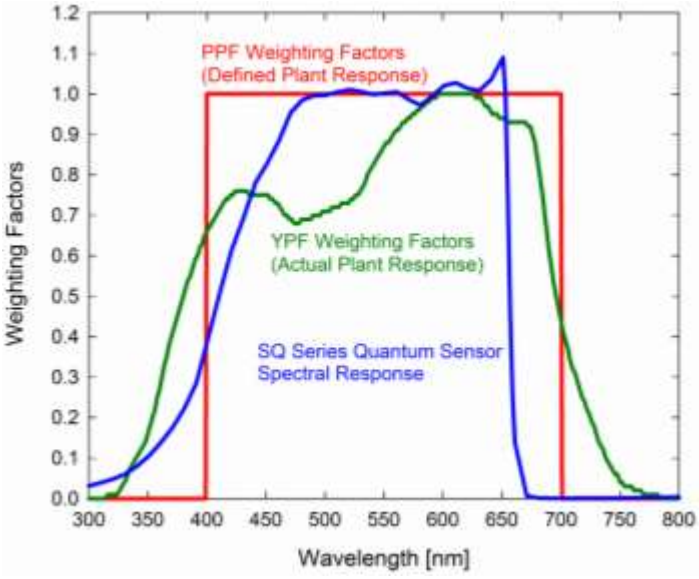
Apogee quantum sensors are calibrated to measure PPFD for either sunlight or electric light. The difference between the calibrations is 14 %. A sensor calibrated for electric lights (calibration source is T5 cool white fluorescent lamps) will read approximately 14 % low in sunlight.

In addition to PPFD measurements, Apogee SQ series quantum sensors can also be used to measure yield photon flux density (YPFD): photon flux weighted according to the plant photosynthetic action spectrum (McCree, 1972) and summed. YPFD is also expressed in units of μmol m^{-2} s^{-1}, and is similar to PPFD, but is typically more closely correlated to photosynthesis than PPFD. PPFD is usually measured and reported because the PPFD spectral weighting function (equal weight given to all photons between 400 and 700 nm; no weight given to photons outside this range) is easier to define and measure, and as a result, PPFD is widely accepted. The calibration factor for YPFD is 10 % lower than the calibration factor for PPFD.

The weighting functions for PPFD and YPFD are shown in the graph below, along with the spectral response of Apogee SQ series quantum sensors. The closer the spectral response matches the defined PPFD or YPFD spectral weighting functions, the smaller spectral errors will be. The table below provides spectral error estimates for PPFD and YPFD measurements from light sources different than the calibration source. The method of Federer and Tanner (1966) was used to determine spectral errors based on the PPFD and YPFD spectral weighting functions, measured sensor spectral response, and radiation source spectral outputs (measured with a spectroradiometer). This method calculates spectral error and does not consider calibration, cosine, and temperature errors.

Federer, C. A., and C. B. Tanner, 1966. Sensors for measuring light available for photosynthesis. Ecology 47:654-657.

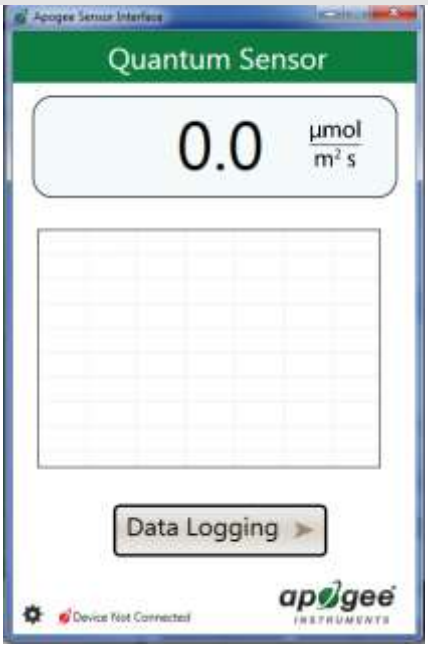
McCree, K. J., 1972. The action spectrum, absorptance and quantum yield of photosynthesis in crop plants. Agricultural Meteorology 9:191-216.



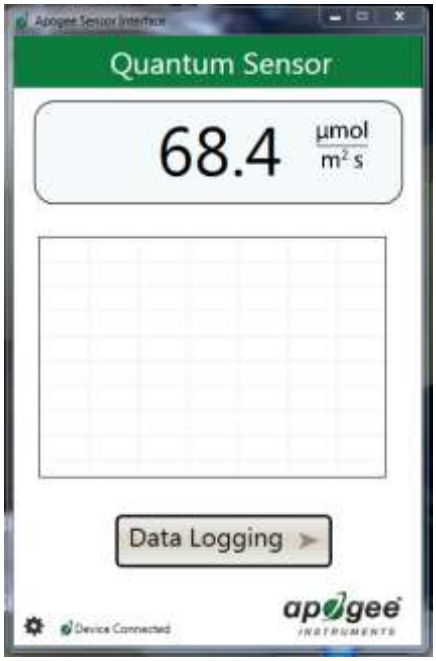
Radiation weighting factors for PPFD (defined plant response to radiation), YPFD (measured plant response to radiation), and Apogee SQ Series quantum sensors (sensor sensitivity to different wavelengths of radiation).

WINDOWS SOFTWARE

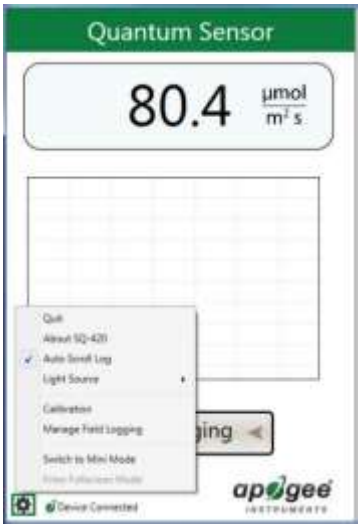
When the SQ-420 sensor is not plugged into the USB port, the software will flash a message in the lower left corner, "Device Not Connected," indicating it cannot establish communication with the sensor.



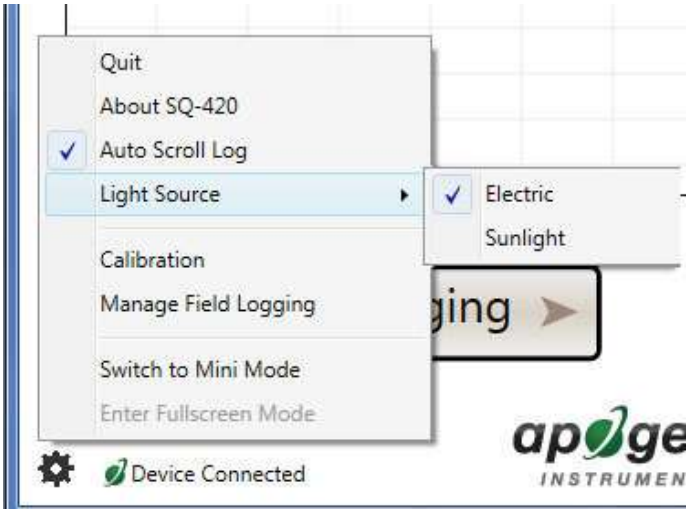
Plug the sensor into a USB port and allow some time for the sensor to automatically establish communication with the software. Once established, the message in the lower left corner will disappear and real-time PAR readings will update on the screen. Moving the sensor closer to a light source should increase the readings, while blocking all light from the sensor should drop the reading to zero.



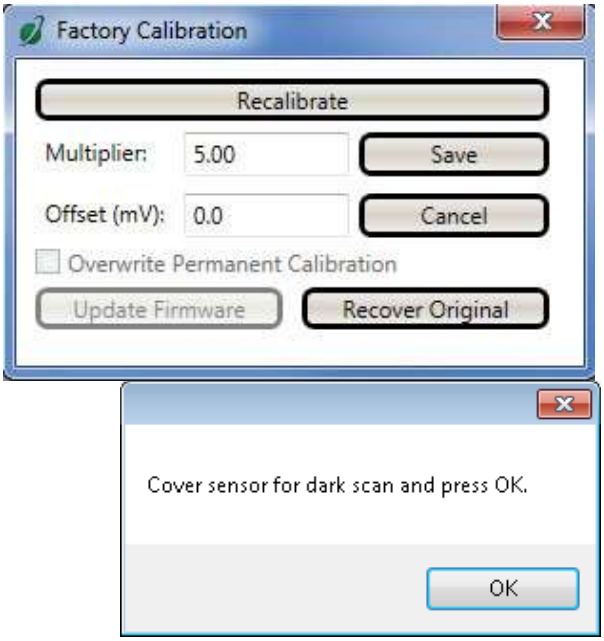
Click the '**Settings**' icon to display the software options.



Clicking **'Light Source'** will allow the user to change the sensor's default calibration reference from Electric to Sunlight. Electric should be selected when measuring most indoor artificial light sources, while Sunlight should be selected when measuring sunlight (such as when evaluating the need for

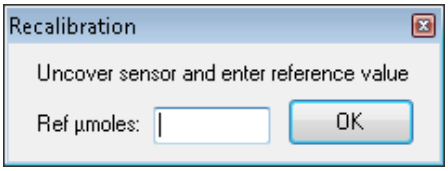


Clicking **'Calibration'** will display the factory calibrated multiplier and offset values. These values are saved in firmware and can be recovered by clicking the 'Recover Original' button. Deriving a new calibration multiplier and offset is accomplished by clicking the 'Recalibrate' button. This is applicable if users want to calibrate the sensor to their own specific light source. Note that a reference PAR value of the light source is required to complete a recalibration.

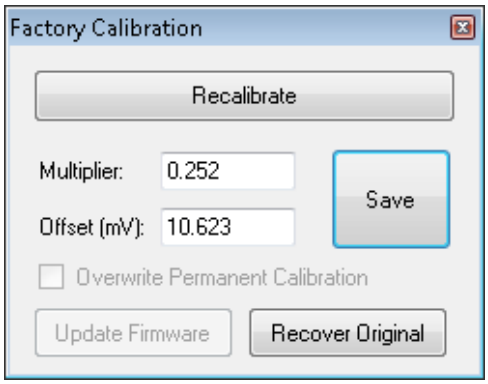


After clicking the 'Recalibate' button the user will be prompted to cover the sensor. Place a dark cap over the sensor and wait for the real-time PAR reading to settle at zero. Click OK.

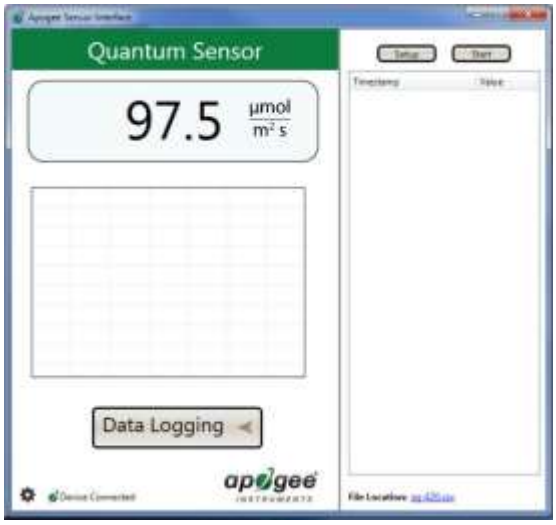
Uncover the sensor and wait for the PAR reading to settle ***before*** entering the reference value. Click OK.



The multiplier and offset values will automatically calculate and update in the appropriate field. Be sure to click 'Save' to retain the new multiplier and offset.

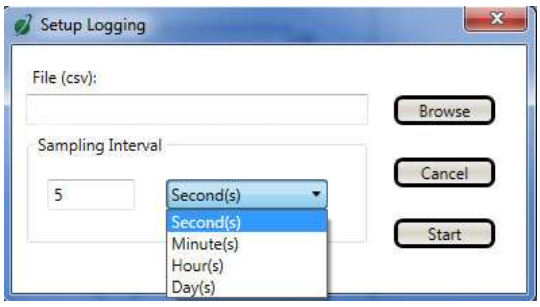


Clicking **'Data Logging'** will allow the user to log interval measurements in a csv file while the software is open and communicating with the sensor.



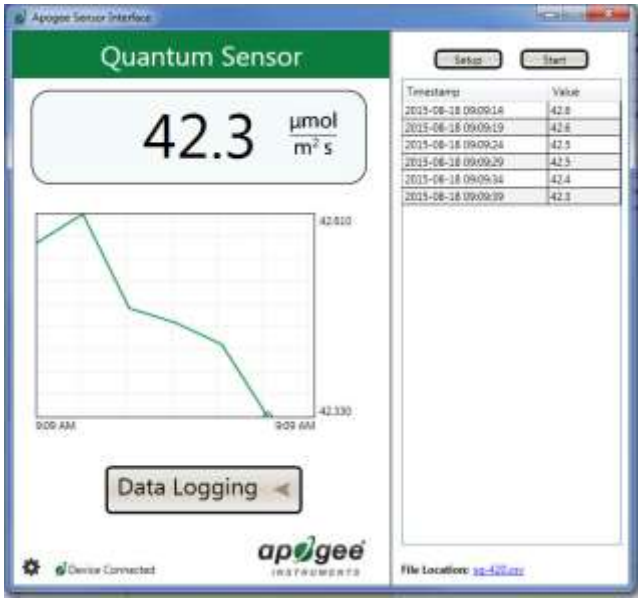
Click 'Setup' and the Setup Logging window appears. Click the 'Browse' button to create or select a csv file.

Select the desired sampling interval. Note that 5 seconds is the minimum interval allowed. Click 'Start'.



The data logging window will start to update at the specified sampling interval and display the Timestamp, Light Source, and Data Value. At the same time, data will be written to the csv file. Note that if the csv file is open in another program new data will not be saved to it.

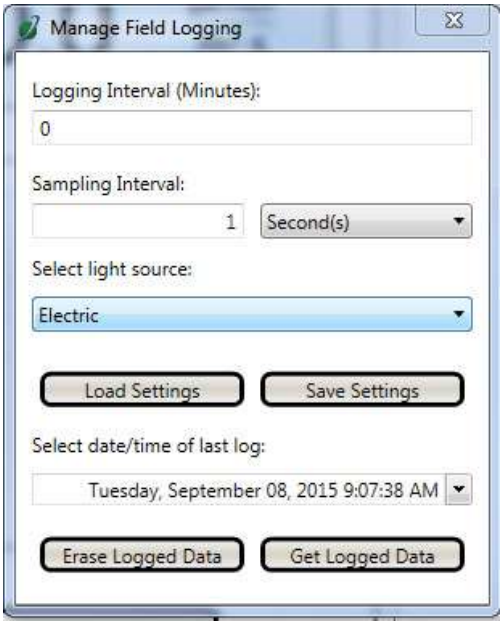
The data logging window can be closed without affecting logged data by clicking the 'Exit' button. The 'Stop' button must be clicked to end data



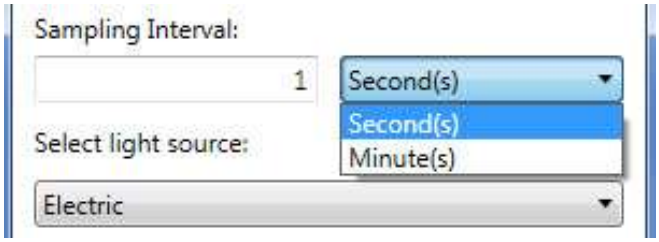
Mini-mode allows you to see the data without having to use as much of the screen.

The about screen tells you the software and firmware versions. These can be used to help troubleshoot if problems arise.

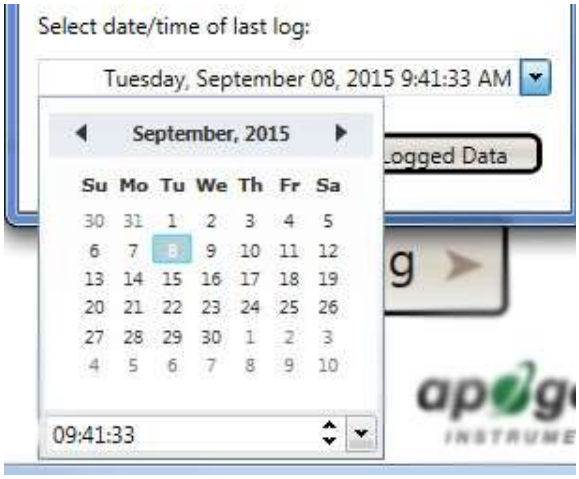
'Manage Field Logging' is used to setup the SQ-420 for use in the field. When the SQ-420 is supplied power from a USB power source (plug or select batteries) it will log data which you can retrieve. Choose the interval that data is saved as well as the interval that data is sampled and the light source used. The shortest sampling interval is 1 second. The longest sampling or logging interval is 1440 minutes (1 day). Click Load settings to see current settings and Save setting to save the settings you want to the sensor. Note: If you don't click save the sensor won't change the settings.



Set the sampling interval in minutes or seconds. The sampling interval is how often a measurement is taken and logging interval is how often the data is saved. The logged data is the average of the samples. The logging interval must be evenly divided by the sampling interval. For example if the logging interval is 5 minutes and the sampling interval is 2 minutes it causes an error. But a sampling interval of 1 minute is acceptable.

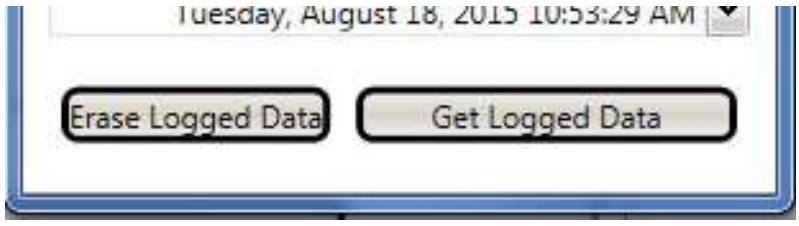


Before clicking 'Get Logged Data' it is important to set the time of the last logged data point. This is used to back calculate the timestamps for the remaining data points. If you just unplugged the sensor and plugged it into the computer the preloaded day and time should be sufficient.



Click 'Get Logged Data' to save the data to your computer. You will be asked where you want to save the data.

Click 'Erase Data' to erase all the save data. This can't be undone.



Spectral Errors for PAR Measurements with Apogee SQ Quantum Sensors:

The SQ-420 quantum sensors are calibrated to measure PAR for either sunlight (natural setting) or electric light. The difference between the calibrations is 14 %. A sensor calibrated for electric lights (calibration source is T5 cool white fluorescent lamps) will read approximately 14 % low in sunlight (natural setting).

Radiation Source (Error Calculated Relative to Sun, Clear Sky)	**PPF Error [%]**	**YPF Error [%]**
Sun (Clear Sky)	0.0	0.0
Sun (Cloudy Sky)	1.4	1.6
Reflected from Grass Canopy	5.7	-6.3
Reflected from Deciduous Canopy	4.9	-7.0
Reflected from Conifer Canopy	5.5	-6.8
Transmitted below Grass Canopy	6.4	-4.5
Transmitted below Deciduous Canopy	6.8	-5.4
Transmitted below Conifer Canopy	5.3	2.6
Radiation Source (Error Calculated Relative to Cool White Fluorescent, T5)		
Cool White Fluorescent (T5)	0.0	0.0
Cool White Fluorescent (T8)	-0.3	-1.2
Cool White Fluorescent (T12)	-1.4	-2.0
Compact Fluorescent	-0.5	-5.3
Metal Halide	-3.7	-3.7
Ceramic Metal Halide	-6.0	-6.4

High Pressure Sodium	0.8	-7.2
Blue LED (448 nm peak, 20 nm full-width half-maximum)	-12.7	8.0
Green LED (524 nm peak, 30 nm full-width half-maximum)	8.0	26.2
Red LED (635 nm peak, 20 nm full-width half-maximum)	4.8	-6.2
Red, Blue LED Mixture (85 % Red, 15 % Blue)	2.4	-4.4
Red, Green, Blue LED Mixture (72 % Red, 16 % Green, 12 % Blue)	3.4	0.2
Cool White Fluorescent LED	-4.6	-0.6
Neutral White Fluorescent LED	-6.7	-5.2
Warm White Fluorescent LED	-10.9	-13.0

Quantum sensors can be a very practical means of measuring PAR from multiple radiation sources, but spectral errors must be considered. The spectral errors in the table above can be used as correction factors for individual radiation sources.

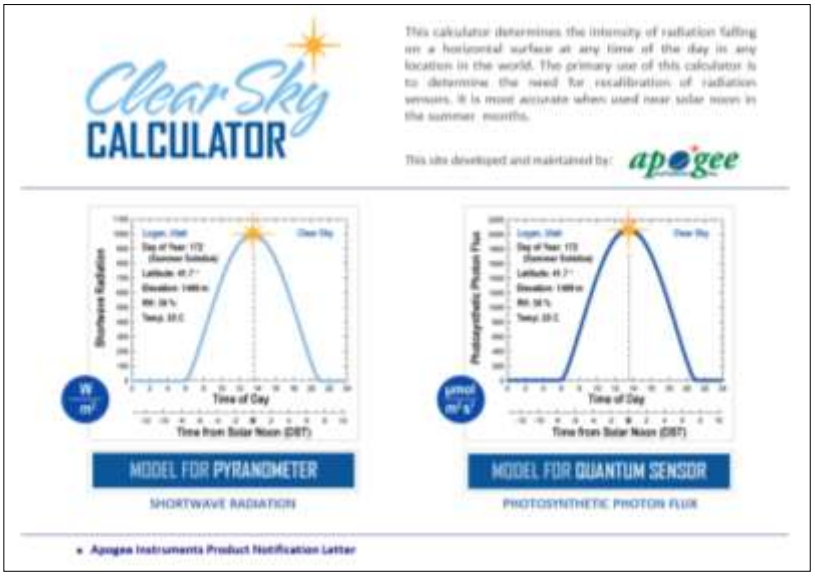
MAINTENANCE AND RECALIBRATION

Moisture or debris on the diffuser is a common cause of low readings. The sensor has a domed diffuser and housing for improved self-cleaning from rainfall, but materials can accumulate on the diffuser (e.g., dust during periods of low rainfall, salt deposits from evaporation of sea spray or sprinkler irrigation water) and partially block the optical path. Dust or organic deposits are best removed using water, or window cleaner and a soft cloth or cotton swab. Salt deposits should be dissolved with vinegar and removed with a soft cloth or cotton swab. **Never use an abrasive material or cleaner on the diffuser.**

The Clear Sky Calculator (www.clearskycalculator.com) can be used to determine the need for quantum sensor recalibration. It determines PPFD incident on a horizontal surface at any time of day at any location in the world. It is most accurate when used near solar noon in spring and summer months, where accuracy over multiple clear and unpolluted days is estimated to be ± 4 % in all climates and locations around the world. For best accuracy, the sky must be completely clear, as reflected radiation from clouds causes incoming radiation to increase above the value predicted by the clear sky calculator. Measured values of PPFD can exceed values predicted by the Clear Sky Calculator due to reflection from the sides and edges of clouds. This reflection increases the incoming radiation. The influence of high clouds typically shows up as spikes above clear sky values, not a constant offset greater than clear sky values.

To determine recalibration need, input site conditions into the calculator and compare PPFD measurements to calculated PPFD values for a clear sky. If sensor PPFD measurements over multiple days near solar noon are consistently different than calculated values (by more than 6 %), the sensor should be cleaned and re-leveled. If PPFD measurements are still different after a second test, email calibration@apogeeinstruments.com to discuss test results and possible return of sensor(s) for recalibration.

Clear Sky Calculator for quantum sensors. Site data are input in blue cells in middle of page and an estimate of PPFD is returned on right-hand side of page.



Homepage of the Clear Sky Calculator. Two calculators are available: one for quantum sensors (PPFD) and one for pyranometers (total shortwave radiation).

Clear Sky Calculator for quantum sensors. Site data are input in blue cells in middle of page and an estimate of PPFD is returned on right-hand side of page.

TROUBLESHOOTING AND CUSTOMER SUPPORT

Cable Length:

Fifteen feet is the maximum cable length that can be built into the sensor.

Modifying Cable Length:

If you required a longer cable length an "active" USB extension cable is required. Please note, the connection between the cables must be made water tight prior to submersion.

Unit Conversion Charts:

Apogee SQ series quantum sensors are calibrated to measure PPFD in units of µmol m^{-2} s^{-1}. It is possible to convert the PPFD value to units of light quantity (e.g., footcandles or lux), but it requires conversion factors that are specific to the radiation source of interest. These conversion factors can be found in the Knowledge Base on Apogee Instruments website (http://www.apogeeinstruments.com/knowledge-base/; scroll down to Quantum Sensors section).

RETURN AND WARRANTY POLICY

RETURN POLICY

Apogee Instruments will accept returns within 30 days of purchase as long as the product is in new condition (to be determined by Apogee). Returns are subject to a 10 % restocking fee.

WARRANTY POLICY

What is Covered
All products manufactured by Apogee Instruments are warranted to be free from defects in materials and craftsmanship for a period of four (4) years from the date of shipment from our factory. To be considered for warranty coverage an item must be evaluated either at our factory or by an authorized distributor.

Products not manufactured by Apogee (spectroradiometers, chlorophyll content meters) are covered for a period of one (1) year.

What is Not Covered
The customer is responsible for all costs associated with the removal, reinstallation, and shipping of suspected warranty items to our factory.

The warranty does not cover equipment that has been damaged due to the following conditions:

1. Improper installation or abuse.

2. Operation of the instrument outside of its specified operating range.

3. Natural occurrences such as lightning, fire, etc.

4. Unauthorized modification.

5. Improper or unauthorized repair.

Please note that nominal accuracy drift is normal over time. Routine recalibration of sensors/meters is considered part of proper maintenance and is not covered under warranty.

Who is Covered
This warranty covers the original purchaser of the product or other party who may own it during the warranty period.

What We Will Do
At no charge we will:

1. Either repair or replace (at our discretion) the item under warranty.

2. Ship the item back to the customer by the carrier of our choice.

Different or expedited shipping methods will be at the customer's expense.

How To Return An Item
1. Please do not send any products back to Apogee Instruments until you have received a Return Merchandise Authorization (RMA) number from our technical support department by calling (435) 792-4700 or by submitting an online RMA form at www.apogeeinstruments.com/tech-support-recalibration-repairs/. We will use your RMA number for tracking of the service item.

2. Send all RMA sensors and meters back in the following condition: Clean the sensor's exterior and cord. Do not modify the sensors or wires, including splicing, cutting wire leads, etc. If a connector has been attached to the cable end,

please include the mating connector – otherwise the sensor connector will be removed in order to complete the repair/recalibration.

3. Please write the RMA number on the outside of the shipping container.

4. Return the item with freight pre-paid and fully insured to our factory address shown below. We are not responsible for any costs associated with the transportation of products across international borders.

5. Upon receipt, Apogee Instruments will determine the cause of failure. If the product is found to be defective in terms of operation to the published specifications due to a failure of product materials or craftsmanship, Apogee Instruments will repair or replace the items free of charge. If it is determined that your product is not covered under warranty, you will be informed and given an estimated repair/replacement cost.

Apogee Instruments, Inc.
721 West 1800 North Logan, UT
84321, USA

OTHER TERMS

The available remedy of defects under this warranty is for the repair or replacement of the original product, and Apogee Instruments is not responsible for any direct, indirect, incidental, or consequential damages, including but not limited to loss of income, loss of revenue, loss of profit, loss of wages, loss of time, loss of sales, accruement of debts or expenses, injury to personal property, or injury to any person or any other type of damage or loss.

This limited warranty and any disputes arising out of or in connection with this limited warranty ("Disputes") shall be governed by the laws of the State of Utah, USA, excluding conflicts of law principles and excluding the Convention for the International Sale of Goods. The courts located in the State of Utah, USA, shall have exclusive jurisdiction over any Disputes.

This limited warranty gives you specific legal rights, and you may also have other rights, which vary from state to state and jurisdiction to jurisdiction, and which shall not be affected by this limited warranty. This warranty extends only to you and cannot by transferred or assigned. If any provision of this limited warranty is unlawful, void or unenforceable, that provision shall be deemed severable and shall not affect any remaining provisions. In case of any inconsistency between the English and other versions of this limited warranty, the English version shall prevail.

This warranty cannot be changed, assumed, or amended by any other person or agreement.