

# apogee

## INSTRUMENTS

OWNER'S MANUAL

## PYRANOMETER

Models SP-110 and SP-230  
(including SS models)



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# CERTIFICATE OF COMPLIANCE

## EU Declaration of Conformity

This declaration of conformity is issued under the sole responsibility of the manufacturer:

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

for the following product(s):

Models: SP-110, SP-230  
Type: Pyranometer

The object of the declaration described above is in conformity with the relevant Union harmonization legislation:

2014/30/EU      Electromagnetic Compatibility (EMC) Directive  
2011/65/EU      Restriction of Hazardous Substances (RoHS 2) Directive

Standards referenced during compliance assessment:

EN 61326-1:2013    Electrical equipment for measurement, control and laboratory use – EMC requirements  
EN 50581:2012    Technical documentation for the assessment of electrical and electronic products with respect to the restriction of hazardous substances

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.

Signed for and on behalf of:  
Apogee Instruments, May 2016



Bruce Bugbee  
President  
Apogee Instruments, Inc.

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## INTRODUCTION

Solar radiation at Earth's surface is typically defined as total radiation across a wavelength range of 280 to 4000 nm (shortwave radiation). Total solar radiation, direct beam and diffuse, incident on a horizontal surface is defined as global shortwave radiation, or shortwave irradiance (incident radiant flux), and is expressed in Watts per square meter ( $\text{W m}^{-2}$ , equal to Joules per second per square meter).

Pyranometers are sensors that measure global shortwave radiation. Apogee SP series pyranometers are silicon-cell pyranometers, and are only sensitive to a portion of the solar spectrum, approximately 350-1100 nm (approximately 80 % of total shortwave radiation is within this range). However, silicon-cell pyranometers are calibrated to estimate total shortwave radiation across the entire solar spectrum. Silicon-cell pyranometer specifications compare favorably to specifications for World Meteorological Organization (WMO) moderate and good quality classifications and specifications for International Organization of Standardization (ISO) second class and first class classifications, but because of limited spectral sensitivity, they do not meet the spectral specification necessary for WMO or ISO certification.

Typical applications of silicon-cell pyranometers include incoming shortwave radiation measurement in agricultural, ecological, and hydrological weather networks, and solar panel arrays.

Apogee Instruments SP series pyranometers consist 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. Sensors are potted solid with no internal air space and are designed for continuous total shortwave radiation measurement on a planar surface in outdoor environments. SP series sensors output an analog voltage that is directly proportional to total shortwave radiation from the sun. The voltage signal from the sensor is directly proportional to radiation incident on a planar surface (does not have to be horizontal), where the radiation emanates from all angles of a hemisphere.

## SENSOR MODELS

This manual covers the unamplified models SP-110 and SP-230 pyranometer sensors that provide millivolt signals. Additional models are covered in their respective manuals.

Model	Signal
<b>SP-110</b>	<b>Self-powered</b>
<b>SP-230*</b>	<b>Self-powered</b>
SP-212	0-2.5 V
SP-214	4-20 mA
SP-215	0-5 V
SP-420	USB
SP-421	SDI-12
SP-422	Modbus

\*Pyranometer model SP-230 is similar to model SP-110, but includes internal heaters designed to keep the diffuser free of precipitation events such as dew or frost.



SP-110



SP-230



Sensor model number and serial number are located near the pigtail leads on the sensor cable. If you need the manufacturing date of your sensor, please contact Apogee Instruments with the serial number of your sensor.

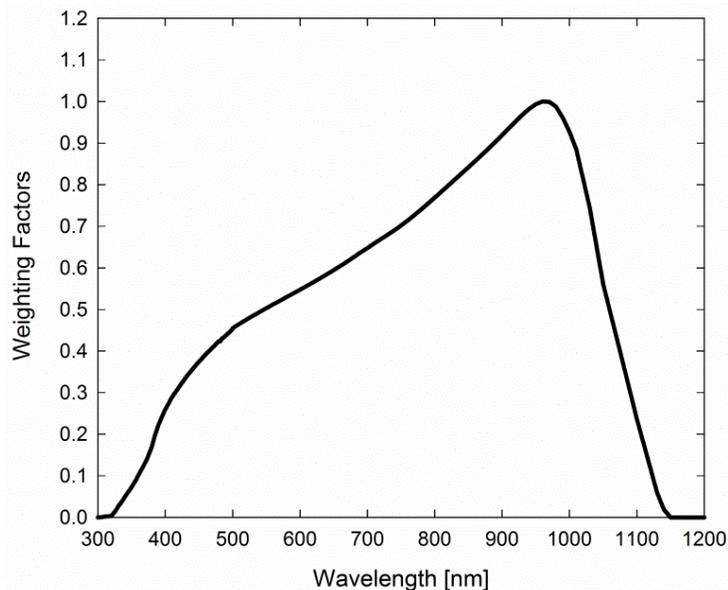
## SPECIFICATIONS

	SP-110	SP-230
Heater	N/A	780 $\Omega$ , 15.4 mA current drain and 185 mW power requirement at 12V DC
Sensitivity	0.2 mV per $W m^{-2}$	
Calibration Factor (Reciprocal of Sensitivity)	5.0 $W m^{-2}$ per mV	
Calibration Uncertainty	$\pm 5\%$ (see Calibration Traceability below)	
Calibrated Output Range	0 to 400 mV	
Measurement Repeatability	Less than 1 %	
Long-term Drift (Non-stability)	Less than 2 % per year	
Non-linearity	Less than 1 % (up to 2000 $W m^{-2}$ )	
Response Time	Less than 1 ms	
Field of View	180°	
Spectral Range	360 to 1120 nm (wavelengths where response is 10% of maximum; see Spectral Response below)	
Directional (Cosine) Response	$\pm 5\%$ at 75° zenith angle (see Cosine Response below)	
Temperature Response	0.04 $\pm$ 0.04 % 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	24 mm diameter; 27.5 mm height	
Mass	90 g (with 5m of lead wire)	
Cable	5 m of two conductor, shielded, twisted-pair wire; additional cable available in multiples of 5 m; santoprene rubber jacket (high water resistance, high UV stability, flexibility in cold conditions); pigtail lead wires	

### Calibration Traceability

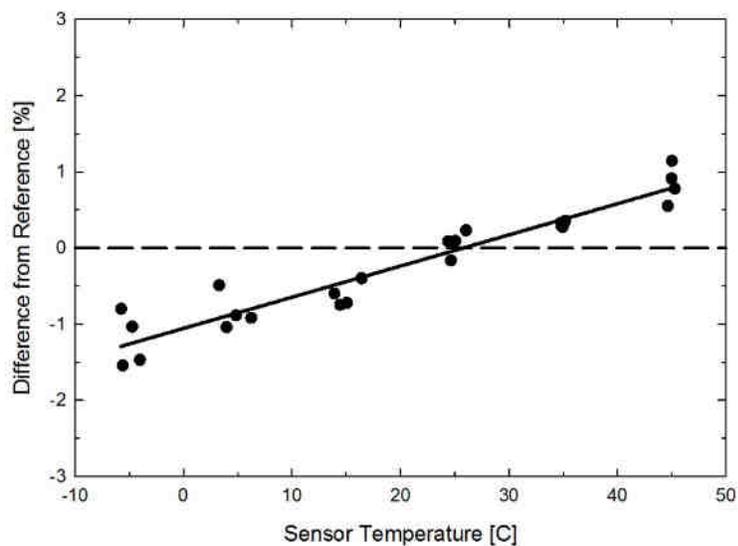
Apogee Instruments SP series pyranometers are calibrated through side-by-side comparison to the mean of four Apogee model SP-110 transfer standard pyranometers (shortwave radiation reference) under high intensity discharge metal halide lamps. The transfer standard pyranometers are calibrated through side-by-side comparison to the mean of at least two ISO-classified reference pyranometers under sunlight (clear sky conditions) in Logan, Utah. Each of four ISO-classified reference pyranometers are recalibrated on an alternating year schedule (two instruments each year) at the National Renewable Energy Laboratory (NREL) in Golden, Colorado. NREL reference standards are calibrated to the World Radiometric Reference (WRR) in Davos, Switzerland.

### Spectral Response



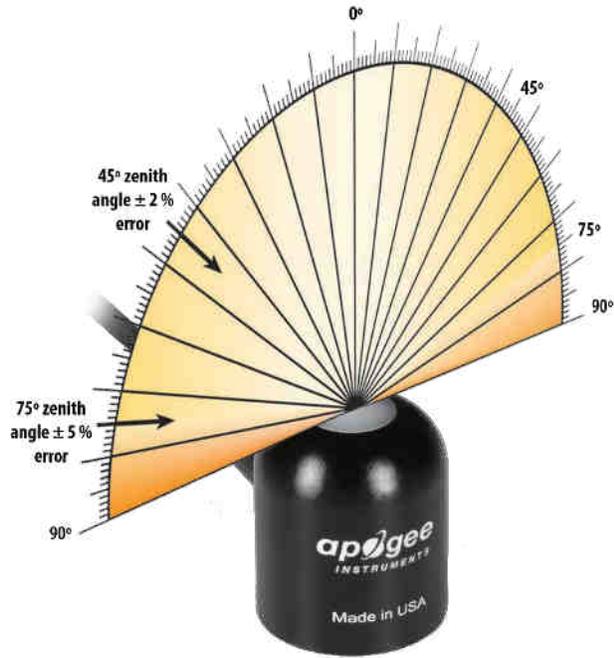
Spectral response estimate of Apogee silicon-cell pyranometers. Spectral response was estimated by multiplying the spectral response of the photodiode, diffuser, and adhesive. Spectral response measurements of diffuser and adhesive were made with a spectrometer, and spectral response data for the photodiode were obtained from the manufacturer.

### Temperature Response

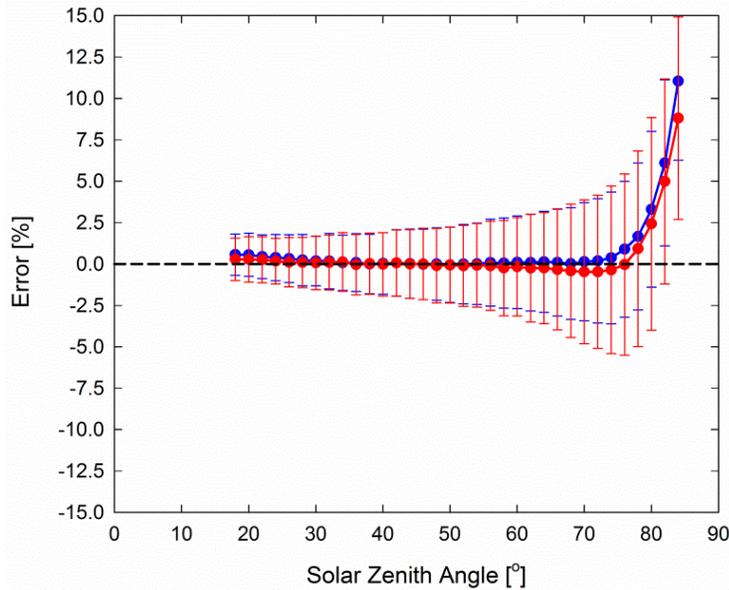


Mean temperature response of four Apogee silicon-cell pyranometers. Temperature response measurements were made at approximately 10 C intervals across a temperature range of approximately -10 to 50 C under sunlight. Each pyranometer had an internal thermistor to measure temperature. At each temperature set point, a reference blackbody pyranometer was used to measure solar intensity.

### Cosine Response



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



Mean cosine response of eleven Apogee silicon-cell pyranometers (**error bars represent two standard deviations above and below mean**). Cosine response measurements were made during broadband outdoor radiometer calibrations (BORCAL) performed during two different years at the National Renewable Energy Laboratory (NREL) in Golden, Colorado. Cosine response was calculated as the relative difference of pyranometer sensitivity at each solar zenith angle to sensitivity at 45° solar zenith angle. The blue symbols are AM measurements, the red symbols are PM measurements.

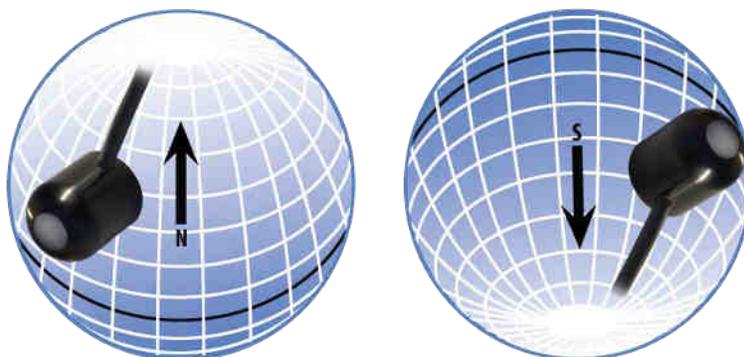
## DEPLOYMENT AND INSTALLATION

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 to level the sensor when used on a flat surface or being mounted to surfaces such as wood. To facilitate mounting on a mast or pipe, the Apogee Instruments model AL-120 Solar Mounting Bracket with Leveling Plate is recommended.

Pyranometer model SP-230 comes with a plastic standoff which should be placed between the sensor head and the leveling plate. The standoff allows for more efficient use of the internal heaters by minimizing possible heating losses through conduction.



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.



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.

## Cable Connectors

Apogee started offering in-line cable connectors on some bare-lead sensors in March 2018 to simplify the process of removing sensors from weather stations for calibration by not requiring the full cable to be uninstalled back to the data logger.

The ruggedized M8 connectors are rated IP67, made of corrosion-resistant marine-grade stainless-steel, and designed for extended use in harsh environmental conditions.

## Instructions

**Pins and Wiring Colors:** All Apogee connectors have six pins, but not all pins are used for every sensor. There may also be unused wire colors inside the cable. To simplify data logger connection, we remove the unused pigtail lead colors at the data logger end of the cable.

If you ever need a replacement cable, please contact us directly to ensure ordering the proper pigtail configuration.

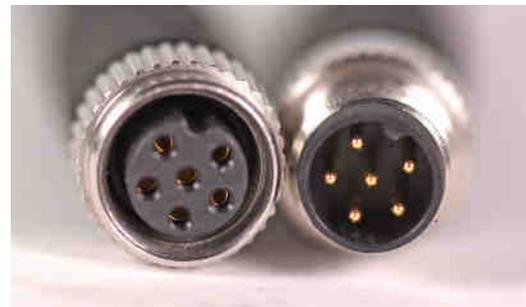
**Alignment:** When reconnecting your sensor, arrows on the connector jacket and an aligning notch ensure proper orientation.

**Disconnection for extended periods:** When disconnecting the sensor for an extended period of time from a station, protect the remaining half of the connector still on the station from water and dirt with electrical tape or other method.

**Tightening:** Connectors are designed to be firmly finger-tightened only. There is an o-ring inside the connector that can be overly compressed if a wrench is used. Pay attention to thread alignment to avoid cross-threading. When fully tightened, 1-2 threads may still be visible.



In-line cable connectors are installed 30 cm from the head (pyranometer pictured)



A reference notch inside the connector ensures proper alignment before tightening.



When sending sensors in for calibration, only send the short end of the cable and half the connector.



Finger-tighten firmly

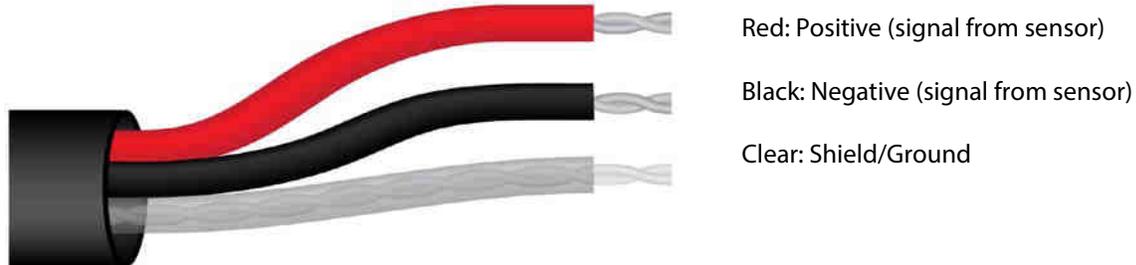
## OPERATION AND MEASUREMENT

Connect the sensor to a measurement device (meter, datalogger, controller) capable of measuring and displaying or recording a millivolt (mV) signal (an input measurement range of approximately 0-250 mV is required to cover the entire range of total shortwave radiation from the sun). In order to maximize measurement resolution and signal-to-noise ratio, the input range of the measurement device should closely match the output range of the pyranometer.

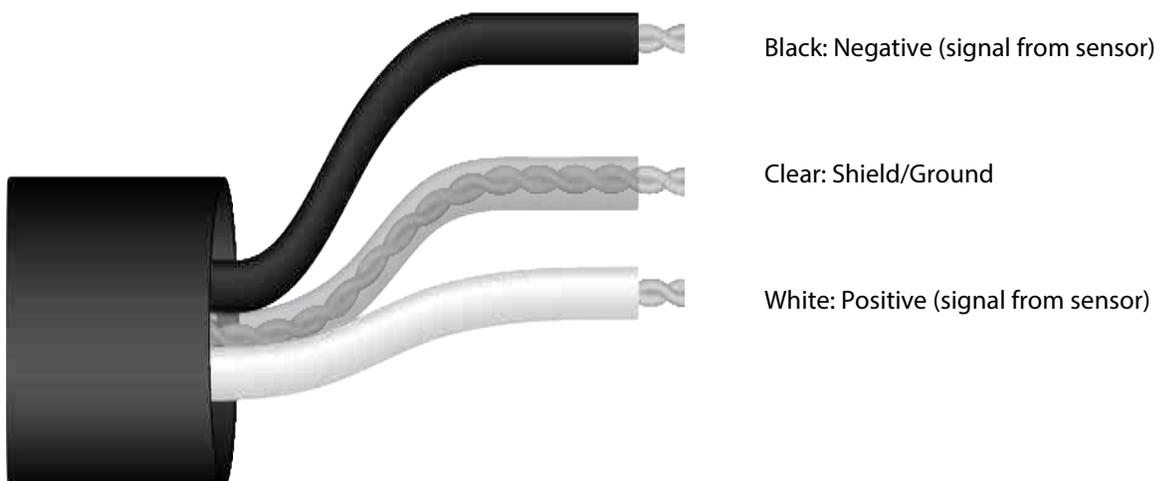
**SP-110: The sensor is self-powered and applying voltage will damage the sensor.**

**VERY IMPORTANT:** Apogee changed all wiring colors of our bare-lead sensors in March 2018 in conjunction with the release of inline cable connectors on some sensors. To ensure proper connection to your data device, please note your serial number or if your sensor has a stainless-steel connector 30 cm from the sensor head then use the appropriate wiring configuration below.

### Wiring for SP-110 Serial Numbers range 0-60050

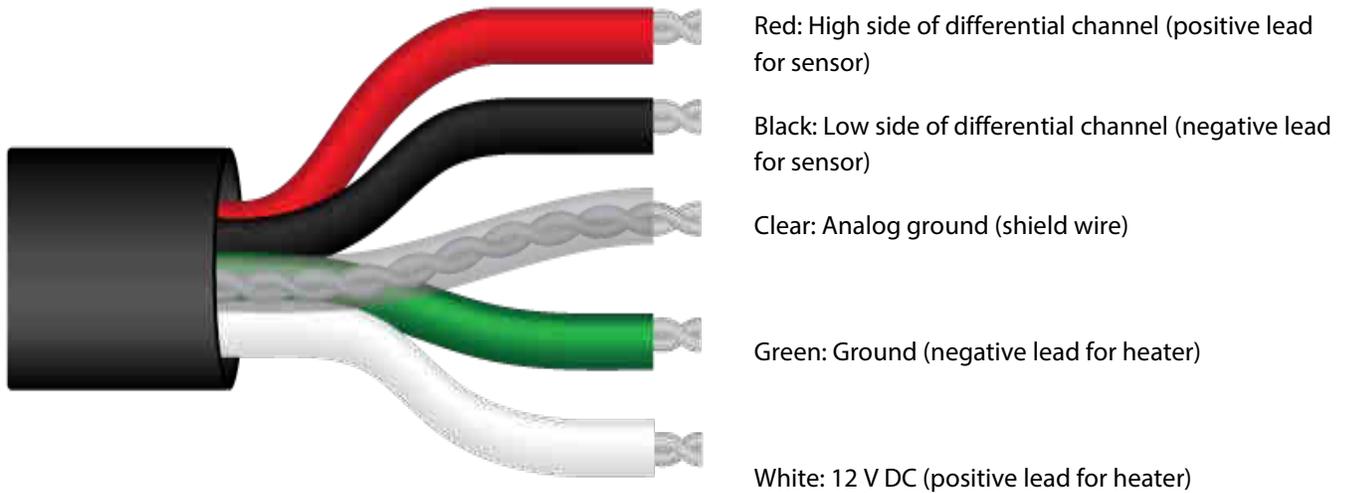


### Wiring for SP-110 Serial Numbers 60051 and above or with a cable connector

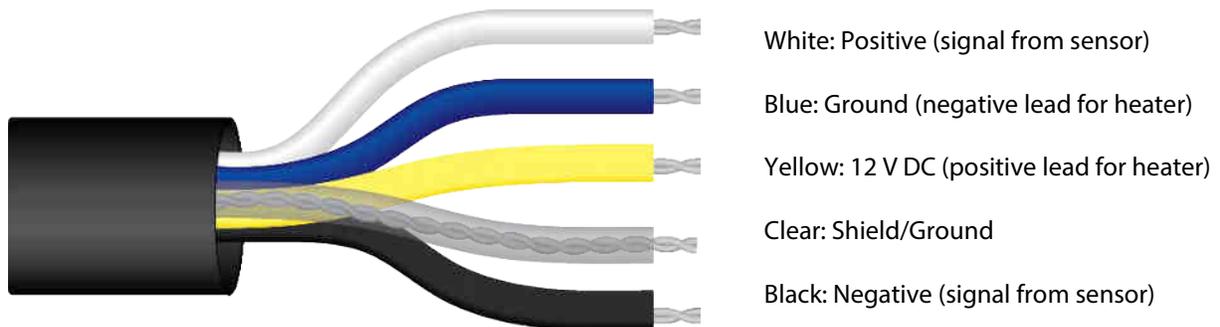


**SP-230: Only apply voltage to the integrated heaters. The sensor is self-powered and applying voltage will damage the sensor.**

**Wiring for SP-230 Serial Numbers range 0-9897**



**Wiring for SP-230 Serial Numbers 9898 and above or with a cable connector**



## Sensor Calibration

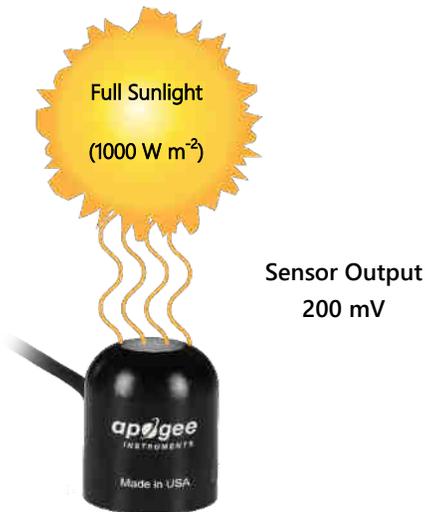
All Apogee un-amplified pyranometer models have a standard calibration factor of exactly:

$$5.0 \text{ W m}^{-2} \text{ per mV}$$

Multiply this calibration factor by the measured mV signal to convert sensor output to shortwave radiation in units of  $\text{W m}^{-2}$ :

$$\text{Calibration Factor (5.0 W m}^{-2} \text{ per mV)} * \text{Sensor Output Signal (mV)} = \text{Total Shortwave Radiation (W m}^{-2}\text{)}$$

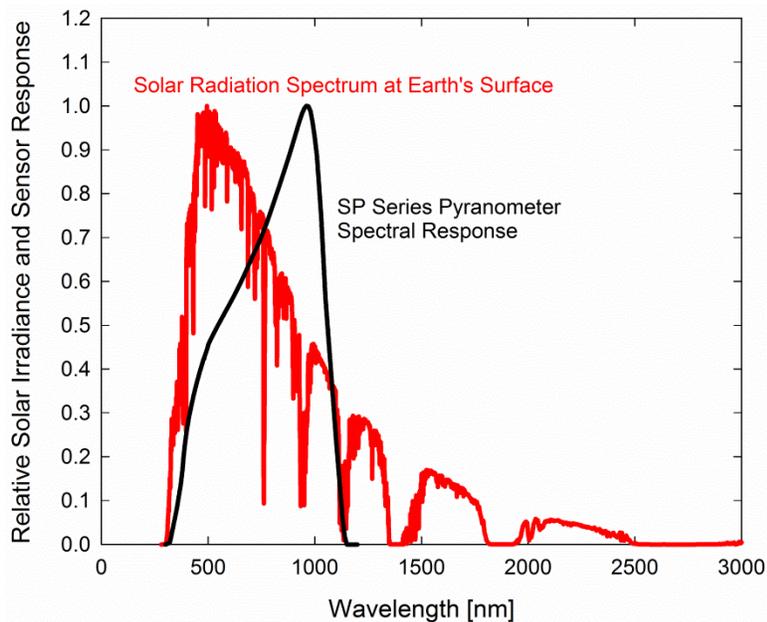
$$5.0 \quad * \quad 200 \quad = \quad 1000$$



Example of total shortwave radiation measurement with an Apogee SP-110 pyranometer. Full sunlight yields total shortwave radiation on a horizontal plane at the Earth's surface of approximately  $1000 \text{ W m}^{-2}$ . This yields an output signal of 200 mV. The signal is converted to shortwave radiation by multiplying by the calibration factor of  $5.0 \text{ W m}^{-2} \text{ per mV}$ .

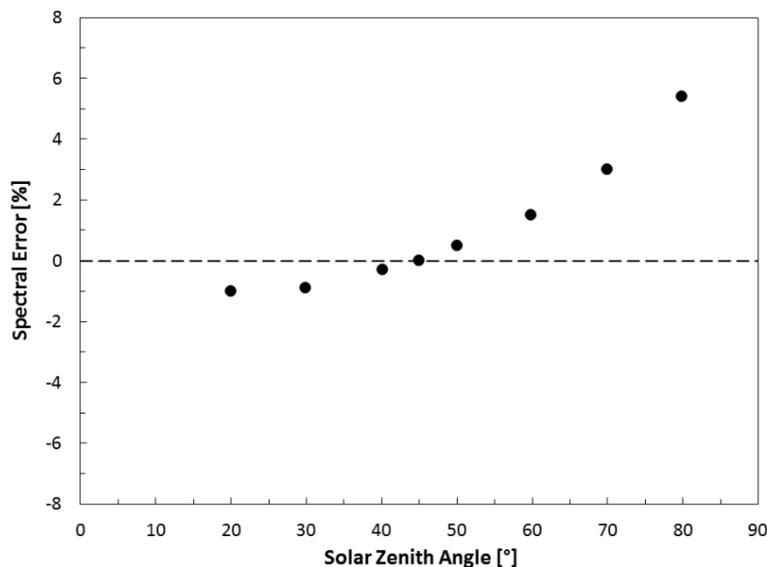
## Spectral Errors for Measurements with Silicon-cell Pyranometers

Apogee SP series pyranometers are calibrated under electric lamps in a calibration laboratory. The calibration procedure simulates calibration under clear sky conditions at a solar zenith angle of approximately  $45^\circ$ . However, due to the limited spectral sensitivity of silicon-cell pyranometers compared to the solar radiation spectrum (see graph below), spectral errors occur when measurements are made in conditions that differ from conditions the sensor was calibrated under (e.g., the solar spectrum differs in clear sky and cloudy conditions, thus measurements in cloudy conditions result in spectral error because sensors are calibrated in clear sky conditions).

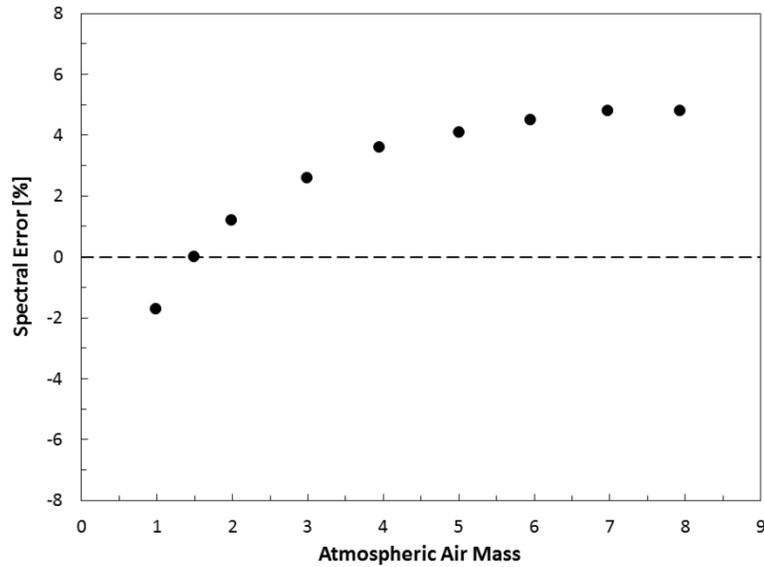


Spectral response of Apogee SP series pyranometers compared to solar radiation spectrum at Earth's surface. Silicon-cell pyranometers, such as Apogee SP series, are only sensitive to the wavelength range of approximately 350-1100 nm, and are not equally sensitive to all wavelengths within this range. As a result, when the spectral content of solar radiation is significantly different than the spectrum that silicon-cell pyranometers were calibrated to, spectral errors result.

Silicon-cell pyranometers can still be used to measure shortwave radiation in conditions other than clear sky or from radiation sources other than incoming sunlight, but spectral errors occur when measuring radiation with silicon-cell pyranometers in these conditions. The graphs below show spectral error estimates for Apogee silicon-cell pyranometers at varying solar zenith angles and varying atmospheric air mass. The diffuser is optimized to minimize directional errors, thus the cosine response graph in the Specifications section shows the actual directional errors in practice (which includes contributions from the spectral shift that occurs as solar zenith angle and atmospheric air mass change with time of day and time of year). The table below provides spectral error estimates for shortwave radiation measurements from shortwave radiation sources other than clear sky solar radiation.



Spectral error for Apogee SP series pyranometers as a function of solar zenith angle, assuming calibration at a zenith angle of 45°.



Spectral error for Apogee SP series pyranometers as a function of atmospheric air mass, assuming calibration at an air mass of 1.5.

### Spectral Errors for Shortwave Radiation Measurements with Apogee SP Series Pyranometers

Radiation Source (Error Calculated Relative to Sun, Clear Sky)	Error [%]
Sun (Clear Sky)	0.0
Sun (Cloudy Sky)	9.6
Reflected from Grass Canopy	14.6
Reflected from Deciduous Canopy	16.0
Reflected from Conifer Canopy	19.2
Reflected from Agricultural Soil	-12.1
Reflected from Forest Soil	-4.1
Reflected from Desert Soil	3.0
Reflected from Water	6.6
Reflected from Ice	0.3
Reflected from Snow	13.7

### Operation of Heater (SP-230)

Apogee model SP-230 pyranometers have an internal heater to allow for sensor heating during precipitation events or under conditions of dew, frost, and snow deposition. The heater is designed to keep the water (liquid and frozen) off the diffuser, though it does not need to be used in order to make measurements of shortwave radiation. However, if the diffuser has water on the surface, errors can result. Continuously powering the heater under conditions that do not require heating will not damage the sensor or influence measurements.

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## MAINTENACE 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.**

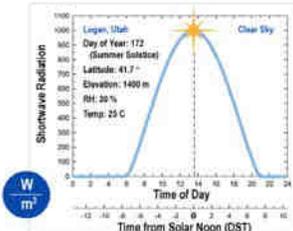
The Clear Sky Calculator ([www.clearskycalculator.com](http://www.clearskycalculator.com)) can be used to determine the need for pyranometer recalibration. It determines total shortwave radiation incident on a horizontal surface at any time of day at any location in the world. It is most accurate when used near solar noon in spring and summer months, where accuracy over multiple clear and unpolluted days is estimated to be  $\pm 4\%$  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 total shortwave radiation can exceed values predicted by the Clear Sky Calculator due to reflection from thin, high clouds and edges of clouds, which enhances incoming shortwave 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 total shortwave radiation measurements to calculated values for a clear sky. If sensor shortwave radiation 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 measurements are still different after a second test, email [calibration@apogeeinstruments.com](mailto:calibration@apogeeinstruments.com) to discuss test results and possible return of sensor(s).



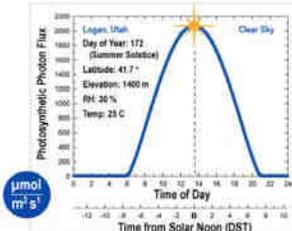
This calculator determines the intensity of radiation falling on a horizontal surface at any time of the day in any location in the world. The primary use of this calculator is to determine the need for recalibration of radiation sensors. It is most accurate when used near solar noon in the summer months.

This site developed and maintained by: 



**MODEL FOR PYRANOMETER**

SHORTWAVE RADIATION



**MODEL FOR QUANTUM SENSOR**

PHOTOSYNTHETIC PHOTON FLUX

Apogee Instruments Product Notification Letter

Homepage of the Clear Sky Calculator. Two calculators are available: One for pyranometers (total shortwave radiation) and one for quantum sensors (photosynthetic photon flux density).



**FOR PYRANOMETERS**

- For best accuracy, comparison should be made on clear, non-polluted, summer days within one hour of solar noon.
- Enter input parameters in the blue cells at right. Definitions are shown below.
- Sensor must be level and perfectly clean. Enter your measured solar radiation in the blue "Measured Shortwave" cell at far right.
- Difference between the model and your sensor is shown in the yellow "DIFFERENCE FROM MODEL" cell at right.
- Run the model on replicate days. Contact Apogee for recalibration if the measured value is more than 5 % different than the estimated value. You will be contacted within two business days.

For a discussion on model accuracy and sensitivity of input parameters, [CLICK HERE](#).

**Input Parameters for Estimating Solar Radiation:**

Latitude =

Longitude =

Longitude<sub>s</sub> =

Elevation =  m

Day of Year =

Time of Day =  (0 min - 0.1 hr)

Daylight Savings =  hr

Air Temperature =  C

Relative Humidity =  %

**Output from Model:**

Model Estimated Shortwave =  W m<sup>-2</sup>

Measured Shortwave =  W m<sup>-2</sup>

**DIFFERENCE FROM MODEL = -1.7 %**

[CONTACT APOGEE FOR RECALIBRATION](#)

Name:

E-mail:

Phone:

Serial #:

Comments:

Please include all requested information.

**INPUT AND OUTPUT DEFINITIONS**

**Latitude** = latitude of the measurement site [degrees]; for southern hemisphere, insert as a negative number; info may be obtained from <http://touchmap.com/ratiorq.html>

**Longitude** = longitude of the measurement site [degrees]; expressed as positive degrees west of the standard meridian in Greenwich, England (e.g. 74° for New York, 26° for Bangkok, Thailand, and 35° for Paris, France).

This site is developed and maintained by: 

[calibration@apogee-inst.com](mailto:calibration@apogee-inst.com)

Clear Sky Calculator for pyranometers. Site data are input in blue cells in middle of page and an estimate of total shortwave radiation is returned on right-hand side of page.

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## TROUBLESHOOTING AND CUSTOMER SUPPORT

### Independent Verification of Functionality

Apogee models SP-110 and SP-230 pyranometers are self-powered devices and output a voltage signal proportional to incident shortwave radiation. A quick and easy check of sensor functionality can be determined using a voltmeter with millivolt (mV) resolution. Connect the positive lead wire from the voltmeter to the white wire from the sensor and the negative (or common) lead wire from the voltmeter to the black wire from the sensor. Direct the sensor diffuser toward a light source and verify the sensor provides a signal. Increase and decrease the distance from the sensor head to the light source to verify that the signal changes proportionally (decreasing signal with increasing distance and increasing signal with decreasing distance). Blocking all radiation from the sensor should force the sensor signal to zero.

The heaters inside Apogee model SP-230 are designed to mitigate effects from snow, frost, and dew by warming the sensor body temperature approximately 3 C above ambient air temperature, while under conditions of no solar loading or radiant heating. A quick and easy check of heater functionality can be accomplished with an ohmmeter. Connect the lead wires of the ohmmeter to the yellow and blue wires from the sensor. The resistance should read approximately  $780 \Omega \pm 1\%$ .

### Compatible Measurement Devices (Dataloggers/Controllers/Meters)

Models SP-110 and SP-230 pyranometers are calibrated with a standard calibration factor of  $5.0 \text{ W m}^{-2}$  per mV, yielding a sensitivity of 0.2 mV per  $\text{W m}^{-2}$ . Thus, a compatible measurement device (e.g., datalogger or controller) should have resolution of at least 0.2 mV, in order to provide shortwave radiation resolution of  $1 \text{ W m}^{-2}$ .

An example datalogger program for Campbell Scientific dataloggers can be found on the Apogee webpage at <http://www.apogeeinstruments.com/content/Pyranometer-Unamplified.CR1>.

### Effect of Cable Length

When the sensor is connected to a measurement device with high input impedance, sensor output signals are not changed by shortening the cable or splicing on additional cable in the field. Tests have shown that if the input impedance of the measurements device is 1 mega-ohm or higher then there is negligible effect on the pyranometer calibration, even after adding up to 100 m of cable. Apogee model SP series pyranometers use shielded, twisted pair cable, which minimizes electromagnetic interference. This is particularly important for long lead lengths in electromagnetically noisy environments.

### Modifying Cable Length

See Apogee webpage for details on how to extend sensor cable length (<http://www.apogeeinstruments.com/how-to-make-a-weatherproof-cable-splice/>).