Product Manual

System

CR-PVS1

PV Soiling Loss Index RTU

Revision: 04/2020

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CR-PVS1 PV Soiling Loss Index RTU

1. Introduction

The CR-PVS1 PV Soiling Loss Index RTU provides solar energy professionals with the information needed to evaluate and manage the impact of soiling. Plant operators can use this information to determine when to clean the array, saving the cost of unnecessary cleanings as well as damage caused by frequent cleanings.

The CR-PVS1 is designed to be at the heart of an independent soiling measurement station or as an add-on peripheral to any new or existing meteorological station. It is delivered field ready and requires no programming. The CR-PVS1 will work with any photovoltaic (PV) panel up to 300 W. Smaller wattage panels can be used. Consult Campbell Scientific before purchasing if using a panel smaller than 20 W. Two highly accurate and rugged back-of-panel sensors are included.

2. Precautions

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

DANGER: Fire, explosion, and severe-burn hazard. 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 lithium batteries properly.

WARNING:

- Protect from overvoltage.
- Protect from water.
- Protect from ESD (electrostatic discharge).

IMPORTANT: Maintain a level of calibration appropriate to the application. Campbell Scientific recommends factory recalibration of the CR-PVS1 every three years.

3. Initial Inspection

The CR-PVS1 ships with the following:

- 2 back-of-panel temperature sensors: 110PV-L15-PT Surface-Mount Thermistors
- Heat-Resistant Kapton Tape with Silicone Adhesive, 5 yd, for securing temperature sensors
- UV-Resistant 8 in. Cable Ties used to secure the temperature sensor cables
- Flat-Bladed Screwdriver for connecting wires to terminals
- 4 grommets and 4 screws for mounting the CR-PVS1 to a Campbell Scientific enclosure backplate

- USB 2.0 Cable Type A Male to Micro B Male for computer communications
- Din-Rail Connector
- CR300 Certificate of Calibration
- 8 GB USB flash drive with *Device Configuration Utility* software
- CR-PVS1 Quick Deploy Guide (also available at *www.campbellsci.com/cr-pvs1*)

Upon receipt of the CR-PVS1, inspect the packaging and contents for damage. File damage claims with the shipping company.

Immediately check package contents. Thoroughly check all packaging material for product that may be concealed. Check model numbers, part numbers, and product descriptions against the shipping documents. Model or part numbers are found on each product. On cabled items, the number is often found at the end of the cable that connects to the measurement device. The Campbell Scientific number may differ from the part or model number printed on the sensor by the sensor vendor. Ensure that you received the expected cable lengths. Contact Campbell Scientific immediately about discrepancies.

4. Overview

The CR-PVS1 uses the short circuit measurement method to provide end users with a simple, lower cost solution that is more easily scalable and deployable in larger numbers on utility scale solar projects using proven methods.

Numerous studies and documents have been published over several decades outlining and testing various methods in order to calculate losses due to soiling, along with their advantages and disadvantages. These studies show that the short circuit current of a solar module is directly proportional to the light intensity and can be used as a reliable method to measure changes in light intensity from reaching the solar cells.

While other methods have been studied, such as I-V curve tracers or maximum power point trackers, these systems can provide minimal accuracy gains only under certain conditions that may not be practical in a field setting. The disadvantage to these systems is their cost and scalability, as they are typically a much more expensive and complicated endeavor.

The CR-PVS1 can act as the system's central measurement and control unit (top of FIGURE 4-1) or as a peripheral unit that is added to any new or existing solar meteorological monitoring system (bottom of FIGURE 4-1). Data transfer from the CR-PVS1 is simple. The CR-PVS1 supports many communication options, including: Internet protocols, Modbus, DNP3, SDI-12, PakBus, and PakBus encryption. (See Section 5.3, *Communications* *(p. 4)*, for a complete list.) Data files (many file formats are available) are sent directly to the cloud via email or FTP, for example.

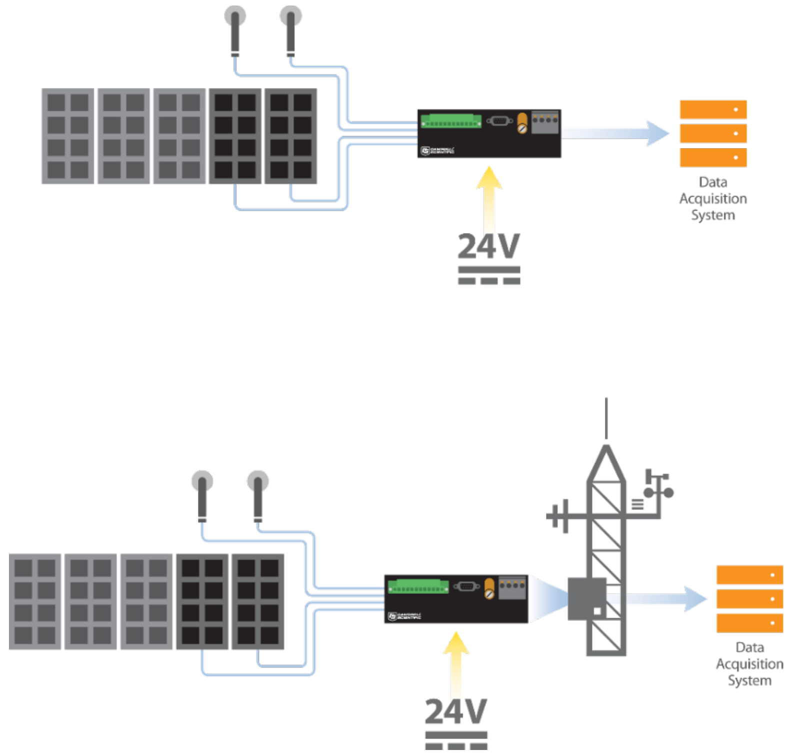


FIGURE 4-1. Example applications

5. Specifications

All CR-PVS1 RTUs are tested and guaranteed to meet electrical specifications in a standard –40 to 70 °C non-condensing environment. Factory recalibration is recommended every three years.

Soiling Loss Index: can detect ≈1%

Maximum Open-Circuit Voltage: 100 V

Maximum Current: 20 A

Measurement Accuracy: ≈2 µV

5.1 Back-of-Panel Temperature Measurements

Measurement Range: –40 to 135 °C

Temperature Uncertainty:

Temperature	Tolerance
–40 to 70 °C	±0.2 °C
71 to 105 °C	±0.5 °C
106 to 135 °C	±1 °C

Steinhart-Hart Linearization Equation Error: 0.0024 °C maximum (at –40 °C)

5.2 Short-Circuit Current Measurements

Current Shunt	
Maximum Operating Temperature:	80 °C
Shunt Accuracy:	±0.25%

5.3 Communications

Modbus RTU	
Format:	RS-232, 19200 bps, 8 data bits, even parity, 1 stop bit
Supported Functions:	03
Modbus Address:	11
Data Type:	32-bit float, CDAB
Internet Protocols:	PPP, ICMP/Ping, Auto-IP(APIPA), IPv6, UDP, TCP, TLS, DHCP Client, SLAAC, DNS Client, Telnet
Additional Protocols Supported:	PakBus, SDI-12, Modbus RTU, Modbus ASCII, Modbus TCP/IP, DNP3 (Custom user-definable over serial.)
USB:	USB micro-B device only, 2.0 full-speed 12 Mbps, for computer connection.
RS-232:	Female RS-232, 9-pin interface

5.4 System

Clock Accuracy:	±1 min per month
Clock Resolution:	1 ms
Program Execution Rate:	30 s

5.5 Power Requirements

Charger Input (CHG):	16 to 32 VDC, current limited at 0.9 A. Power converter or solar panel input.
External Batteries (BAT):	12 VDC, lead-acid 7 Ah battery, typical
Internal Lithium Battery:	3 V coin cell CR2016 (Energizer) for battery-backed clock. 6-year life with no external power source.
Typical Power Requirements	
Idle:	1.5 mA
Active 1 Hz scan with analog measurements:	5 mA
USB Power (USB):	For programming and limited functionality

5.6 Compliance

View compliance documents at *www.campbellsci.com/cr-pvs1*.

Shock and Vibration: ASTM D4169-09

Protection: IP30

5.7 Physical

Width: 20.3 cm (8 in); 21.6 cm (8.5 in) with mounts

Height: 6.3 cm (2.5 in)

Depth: 14 cm (5.5 in)

6. Installation

TABLE 6-1 provides solar panel wiring and TABLE 6-2 provides 110PV back-of-panel-temperature sensor wiring. The Quick Deploy Guide also includes the wiring and other installation and configuration information. *Device Configuration Utility* software is required. This can be installed from the USB sent with the CR-PVS1. It is also available for download at *www.campbellsci.com/devconfig*.

NOTE Download the Quick Deploy Guide at *www.campbellsci.com/cr-pvs1*.

DANGER **To prevent injury, completely cover the PV panels to limit output and current and voltage during installation. Do not short PV panel + and – wires.**

TABLE 6-1. Solar Panel Wire Color, Function, and CR-PVS1 Connections

Solar Panel	Wire Color	Function	CR-PVS1 Terminal
REF	Red	+	**REF Panel +**
	Black	–	**REF Panel –**
TEST	Red	+	**Test Panel +**
	Black	–	**Test Panel –**

TABLE 6-2. 110PV Wire Color, Function, and CR-PVS1 Connections			
Sensor	**Wire Color**	**Function**	**CR-PVS1 Terminal**
REF	Black	Power	**VX1**
	Red	Signal	**SE1**
	Violet	Ground	**G**
	Clear	Shield	**G**
TEST	Black	Power	**VX2**
	Red	Signal	**SE2**
	Violet	Ground	**G**
	Clear	Shield	**G**

The CR-PVS1 has a Modbus RTU output. For the complete Modbus Register Map, see Appendix B, *Modbus Register Map* *(p. B-1)*.

7. Operation

7.1 Measurement

To estimate soiling loss index (SLI), the CR-PVS1 system compares the outputs and temperatures of two identical PV panels mounted side by side: one clean, and the other soiled naturally.

Current measurements and back-of-panel temperature measurements are made every 30 seconds. To make the current measurements, both panels are short-circuited for 5 seconds using a solid-state relay. Short-circuit current is measured with a precision current-sensing shunt. To help minimize PV panel degradation, the panel is maintained in an open-circuit hold state between measurements.

From short-circuit current and back-of-panel temperature, the effective irradiance of each panel is calculated in accordance with IEC 60904, and the SLI is calculated according to equation 7-2.

A daily average SLI is calculated, available for SCADA (supervisory control and data acquisition), and stored in onboard memory. For immediate feedback, a real-time index and quality factor are available. Raw measured data are stored and available for analysis or independent post-processing. Available values are shown in Appendix A, *Glossary of Variable Names* *(p. A-1)*.

In accordance with IEC 60904, the CR-PVS1 calculates the daily soiling loss index during the hour before and the hour after solar noon and only includes the values showing effective irradiance greater than 500 W/m^2 to minimize the effects from the zenith angle of the sun, PV panel current dependence on irradiance level, and air mass density. The CR-PVS1 also filters out data that is classified as unstable (IEC 60904), such as data during cloud cover. A variable, ***Stable_Data_Count***, increments when all criteria are met.

FIGURES 7-1 through 7-5 show the importance of filtering data based on stability of irradiance as well as back of module temperature in accordance with IEC 60904-2. FIGURES 7-1 and 7-2 show effective irradiance calculated from the short-circuit currents. FIGURES 7-3 and 7-4 show the filtered data based on stability conditions. In FIGURE 7-5, both modules were cleaned at record number 650. The soiling index after cleaning is 0.003 (±0.16) % on clear sky and 0.000 (±0.16) % on the variable sky conditions. This is an indication of the lowest level of soling loss that can be detected.

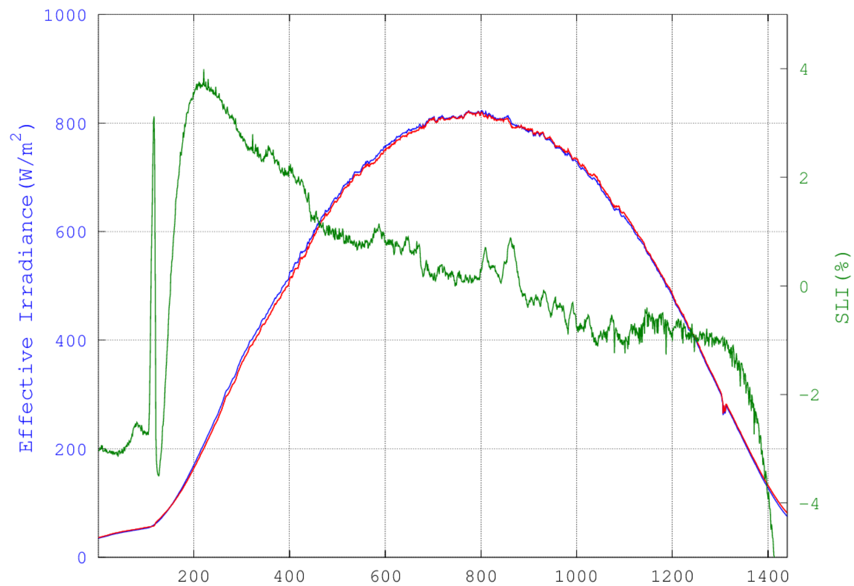


FIGURE 7-1. Effective Irradiance as calculated from short circuit current of the PV modules on a clear sky day

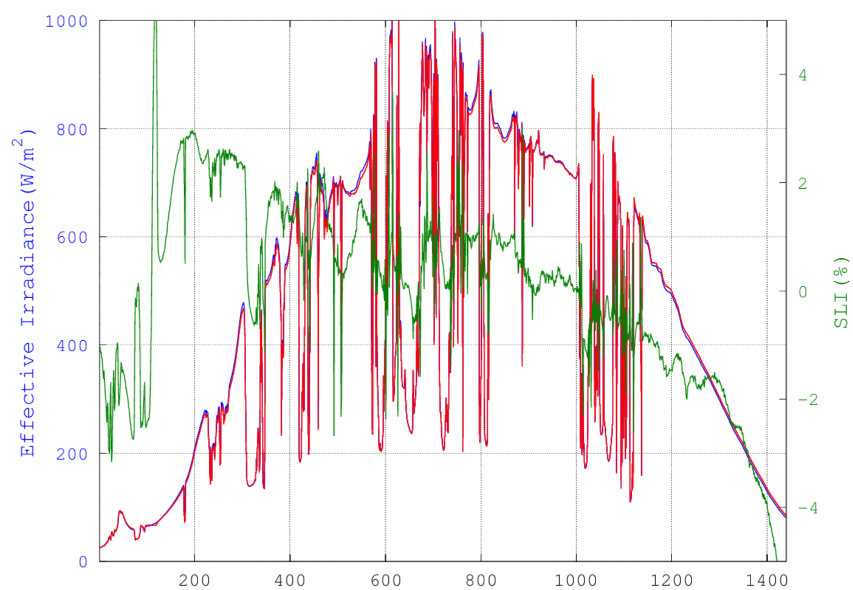


FIGURE 7-2. Effective Irradiance and SLI on a cloudy day

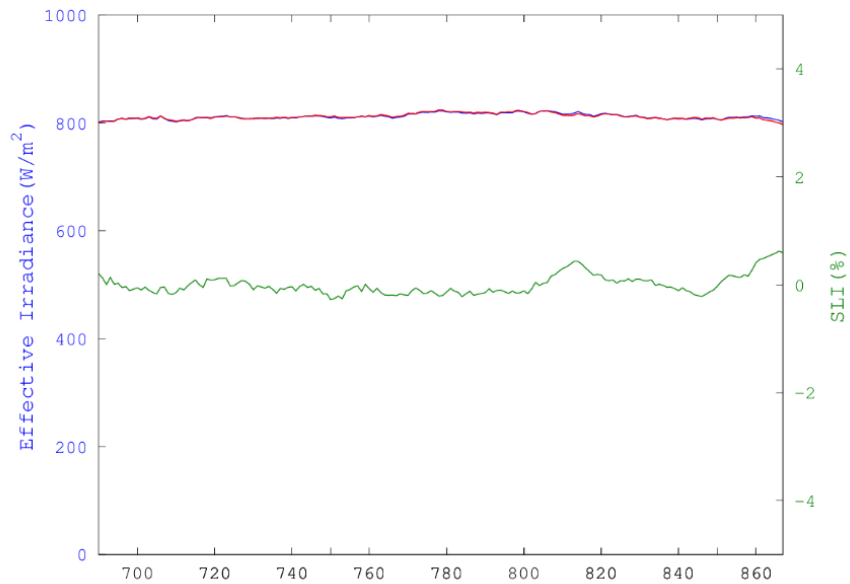


FIGURE 7-3. Effective irradiance and SLI during ±1 hour of solar noon and Geffref > 800 W/m22

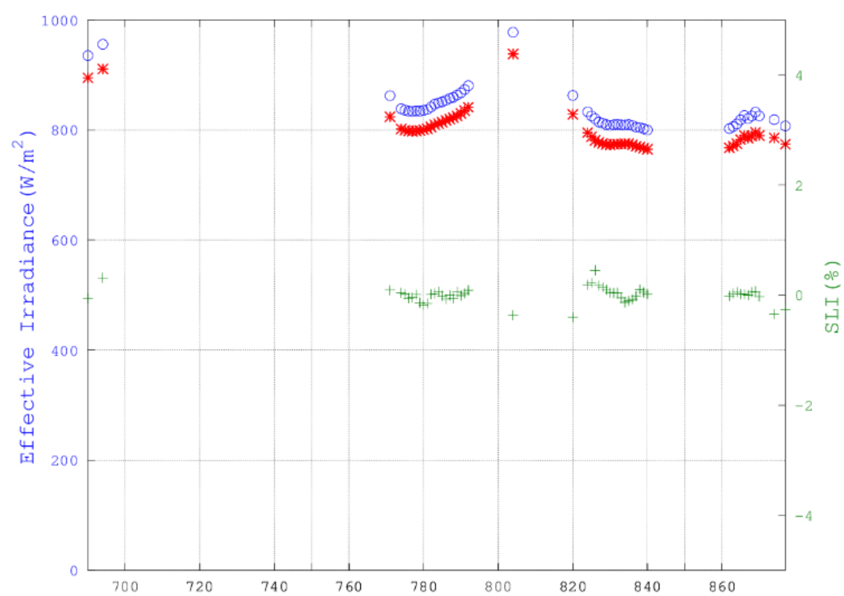


FIGURE 7-4. Geff and SLI taken during a cloudy day with Geffref > 800 w/m^2 during ±1 hour of solar noon

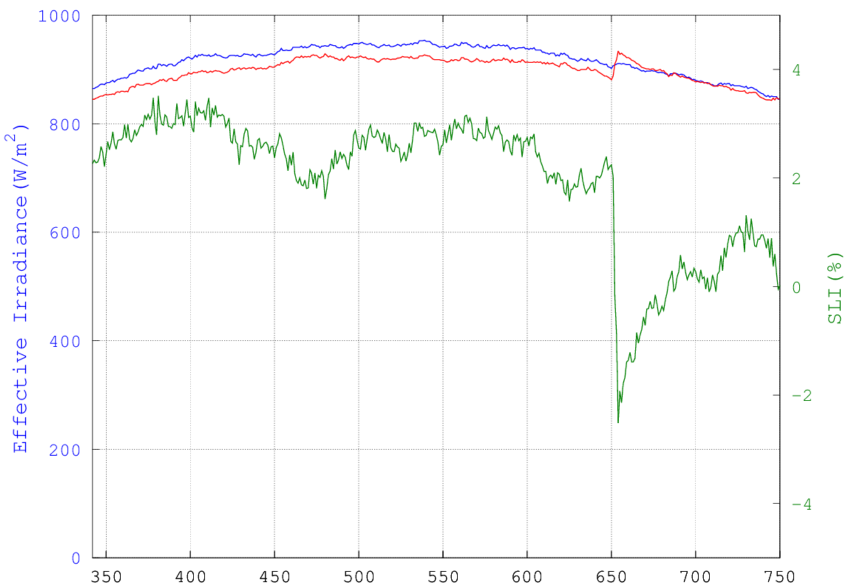


FIGURE 7-5. Change in SLI after a cleaning event. Both modules were cleaned at a time corresponding to the record number 650.

7.2 Soiling Loss Index Details

In terms of quantities that can be measured directly from a PV panel, soiling loss index (SLI) is defined as the loss in the irradiance reaching the solar cells of a PV panel. If all other factors are the same, this loss is primarily due to the loss in transmission properties of the glass as a result of soiling.

The irradiance is calculated from short-circuit current as

$$G_{eff} = I_{SC} \frac{[1 - \alpha(T - T_0)]}{I_{SC,STC}} \qquad \text{7-1}$$

Where G_{eff}: effective irradiance reaching the solar cells

I_{SC}: measured short-circuit current of the panel

$I_{SC,STC}$: short-circuit current at standard test conditions (STC)

T: back-of-panel temperature

T_0: back-of-panel temperature at STC, typically 25 °C

α: temperature coefficient of short-circuit current

The SLI uses the effective irradiances of a clean reference panel and a dirty test panel. It is defined as

$$SLI = \left(1 - \frac{G_{eff,Test}}{G_{eff,Ref}}\right) \times 100\% \qquad \text{7-2}$$

Where $G_{eff,Ref}$ is the effective irradiance calculated from the clean reference panel, and $G_{eff,Test}$ is the effective irradiance calculated from the test panel.

8. Maintenance

For more accurate soiling-rate estimations, clean the reference (clean) panel as often as the pyranometer, a minimum of once per week. Clean with distilled water and a lint-free cloth.

8.1 Offset Correction

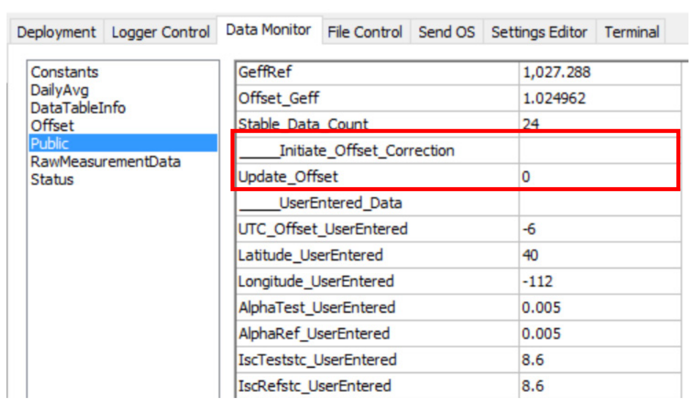
PV panels often differ in power output under identical conditions, even when they are from the same batch of the same model. This offset in power output can be determined upon installation and updated after each cleaning. The procedure determines the offset, and then implements a correction factor into the measurement sequence to remove any effects that may be caused by the offset.

NOTE Carefully clean both panels before initiating this process. Cleaning should be completed before 11 a.m.

1. Connect to the CR-PVS1 using *Device Configuration Utility*. In the **Device Type** list, select **CR300 Series**. Follow the steps shown in the right panel of the window.

2. Once connected, select the **Data Monitor** tab. Click **Public** in the table list.

3. Double-click on the value in the **Update_Offset** field. Enter **1** and press **Enter**.



4. Results will be available with the next measurements.

Appendix A. Glossary of Variable Names

Variable Name	Description
RTU_Internal_Temp	Panel temperature of CR-PVS1, °C
RTU_Voltage	Battery voltage of CR-PVS1, VDC
Soiling_Loss_Index_Corrected	Soiling loss index with offset correction applied, %
Soiling_Loss_Index_Raw	Soiling loss index without offset correction applied, %
Live_Index_Corrected	Real-time index of reference to test panel with offset correction applied, %
Live_Index_Raw	Real-time index of reference to test panel without offset correction applied, %
Stable_Data_Check	Variable indicating if environmental conditions are stable, True (–1)/False (0)
Time_Status	Variable indicating if the time of day is appropriate for performing soiling loss index calculations
Geff_Status	Variable indicating if the measured effective irradiance is appropriate for performing soiling loss index calculations
Isc_Status	Variable indicating if the measured short-circuit current is appropriate for performing soiling loss index calculations
Temp_Status	Variable indicating if the measured back-of-panel temperature is appropriate for performing soiling loss index calculations
IscTest	Short-circuit current of test panel, Amps
IscRef	Short-circuit current of reference panel, Amps
TempTest	Back-of-panel temperature of test panel, °C
TempRef	Back-of-panel temperature of reference panel, °C
GeffTest	Effective irradiance of test panel, W/m^2
GeffRef	Effective irradiance of reference panel, W/m^2
Offset_Geff	Measured offset between reference and test panels, %
Stable_Data_Count	Incrementally counts when conditions are appropriate for performing soiling loss index
Update_Offset	Boolean variable that user triggers when the offset correction is to be performed
UTC_Offset_UserEntered	User-entered UTC offset of site location, hours
Latitude_UserEntered	User-entered latitude of site location
Longitude_UserEntered	User-entered longitude of site location
AlphaTest_UserEntered	Published panel short circuit current (Isc) temperature coeffecient of the test panel (if published in units of %/°C, then enter published value/100)
AlphaRef_UserEntered	Published panel short circuit current (Isc) temperature coeffecient of the reference panel (if published in units of %/°C, then enter published value/100)
IscTeststc_UserEntered	Published panel short-circuit current (Isc) of the test panel at STC
IscRefstc_UserEntered	Published panel short-circuit current (Isc) of the reference panel at STC
LocalSolarNoon	Solar noon of site location, as determined by user-entered site location data

Appendix B. Modbus Register Map

	Parameter	Description	Register Start	Register Stop	Low Range	High Range	Units
ModbusData(1)	Minute	HeartBeat	40001	40002	0	59	Seconds
ModbusData(2)	Soiling_Loss_Index_Isc	Soiling Loss Index Isc	40003	40004	–20	20	%
ModbusData(3)	Soiling_Loss_Index_Geff	Soiling Loss Index Geff	40005	40006	–20	20	%
ModbusData(4)	IscTest	IscTest, Measured short circuit current from the dirty panel	40007	40008	–10	10	Amp
ModbusData(5)	IscRef	IscRef, Measured short circuit current from the clean panel	40009	40010	–10	10	Amp
ModbusData(6)	TempTest	TempTest	40011	40012	–30	80	°C
ModbusData(7)	TempRef	TempRef	40013	40014	–30	80	°C
ModbusData(8)	GeffTest	GeffTest, Effective Irradiance received by the dirty panel	40015	40016	0	1200	W/m^2
ModbusData(9)	GeffRef	GeffRef, Effective Irradiance received by the clean panel	40017	40018	0	1200	W/m^2
ModbusData(10)	Offset_Isc	Offset in Isc between the clean and test panels, when both are clean	40019	40020	1	10	No Units
ModbusData(11)	Offset_Geff	Offset in Geff between the clean and test panels, when both are clean	40021	40022	1	10	
ModbusData(12)	Update_Offset	Update Offset	40023	40024	0	1	
ModbusData(13)	UTC_Offset_UserEntered	UTC Offset of the site, User Entered	40025	40026	–12	12	hrs
ModbusData(14)	Latitude_UserEntered	Latitude of the site, User Entered	40027	40028			degrees
ModbusData(15)	Longitude_UserEntered	Longitude of the site User Entered	40029	40030			degrees
ModbusData(16)	TempCoeffIscTest_UserEntered	Temperature Coefficient of Isc for the Test panel, User Entered	40031	40032	0	No Max	Amp
ModbusData(17)	TempCoeffIscRef_UserEntered	Temperature Coefficient of Isc for the clean panel, User Entered	40033	40034	0	No Max	Amp
ModbusData(18)	IscTeststc_UserEntered	Short circuit current of test panel at STC, User Entered	40035	40036	0.5	20	Amp
ModbusData(19)	IscRefstc_UserEntered	Short circuit current of clean panel at STC, User Entered	40037	40038	0.5	20	Amp
ModbusData(20)	HrSolNoonOffset_UserEntered	Offset from solar noon for daily average	40039	40040	0	2	hrs
ModbusData(21)	GeffThreshold_UserEntered	Threshold in effective irradiance User Entered	40041	40042	100	500	W/m^2
ModbusData(22)	RTU_Voltage	RTU Battery Voltage	40043	40044	9	13	Volts
ModbusData(23)	RTU_Internal_Temp	RTU Internal Temp	40045	40046	-40	70	°C
ModbusData(24)	LocalSolarNoon	Local Solar Noon	40047	40048	12:00	13:00	hrs

Limited Warranty

Products manufactured by Campbell Scientific are warranted by Campbell Scientific to be free from defects in materials and workmanship under normal use and service for twelve months from the date of shipment unless otherwise specified on the corresponding product webpage. See Product Details on the Ordering Information pages at *www.campbellsci.com*. Other manufacturer's products, that are resold by Campbell Scientific, are warranted only to the limits extended by the original manufacturer.

Refer to *www.campbellsci.com/terms#warranty* for more information.

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Logan, Utah 84321-1784

For all returns, the customer must fill out a "Statement of Product Cleanliness and Decontamination" form and comply with the requirements specified in it. The form is available from our website at *www.campbellsci.com/repair*. A completed form must be either emailed to *repair@campbellsci.com* or faxed to (435) 227-9106. Campbell Scientific is unable to process any returns until we receive this form. If the form is not received within three days of product receipt or is incomplete, the product will be returned to the customer at the customer's expense. Campbell Scientific reserves the right to refuse service on products that were exposed to contaminants that may cause health or safety concerns for our employees.

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, 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.

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.

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.

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.

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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Email: info@campbellsci.de
Website: www.campbellsci.de

India

Location: New Delhi, DL India
Phone: 91.11.46500481.482
Email: info@campbellsci.in
Website: www.campbellsci.in

South Africa

Location: Stellenbosch, South Africa
Phone: 27.21.8809960
Email: sales@campbellsci.co.za
Website: www.campbellsci.co.za

Spain

Location: Barcelona, Spain
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Email: info@campbellsci.es
Website: www.campbellsci.es

Thailand

Location: Bangkok, Thailand
Phone: 66.2.719.3399
Email: info@campbellsci.asia
Website: www.campbellsci.asia

UK

Location: Shepshed, Loughborough, UK
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