Product Manual

Sensor

CS320

Digital Thermopile Pyranometer

Revision: 09/2019

RELIABLE SINCE 1974 MONITORING

CAMPBELL SCIENTIFIC

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Assistance

Products may not be returned without prior authorization. The following contact information is for US and international customers residing in countries served by Campbell Scientific, Inc. directly. Affiliate companies handle repairs for customers within their territories. Please visit www.campbellsci.com to determine which Campbell Scientific company serves your country.

To obtain a Returned Materials Authorization (RMA) number, contact CAMPBELL SCIENTIFIC, INC., phone (435) 227-9000. Please write the issued RMA number clearly on the outside of the shipping container. Campbell Scientific's shipping address is:

CAMPBELL SCIENTIFIC, INC.
RMA#_____
815 West 1800 North
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 or by telephoning (435) 227-9000 (USA). 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

- 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.

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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1. Introduction

The CS320, manufactured by Apogee Instruments, consists of a thermopile detector, acrylic diffuser, and heater. The thermopile has a black surface that uniformly absorbs solar radiation across the shortwave solar spectrum from 385 to 2105 nm. The CS320 provides onboard storage of digital calibration data and has a digital SDI-12 output that can be read by most Campbell Scientific data loggers. A detachable cable allows easier field servicing.

> **NOTE:**
> This manual provides information only for CRBasic data loggers. For retired Edlog data logger support, contact Campbell Scientific.

2. Precautions

- READ AND UNDERSTAND the Safety (p. iii) section at the front of this manual.
- Care should be taken when opening the shipping package to not damage or cut the cable jacket. If damage to the cable is suspected, contact Campbell Scientific.
- Remove the green cap after installing the sensor. Save this cap for shipping or storing the sensor.
- Handle the sensor carefully when cleaning. Be careful not to scratch the surface of the sensor.

3. Initial inspection

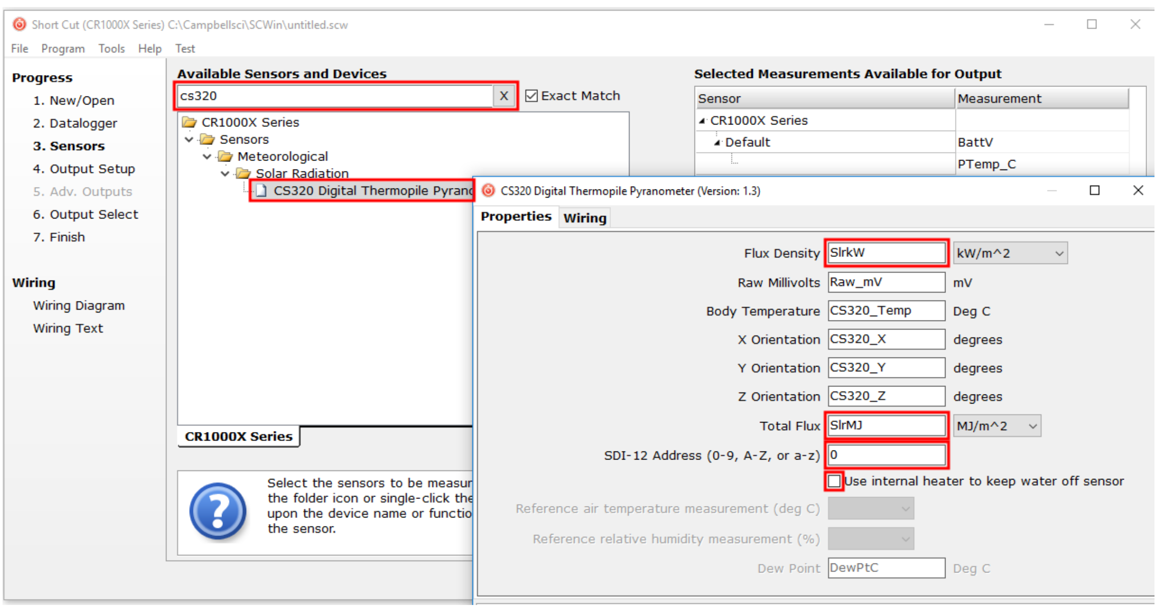
Upon receipt of the CS320, inspect the packaging and contents for damage. File damage claims with the shipping company.

4. QuickStart

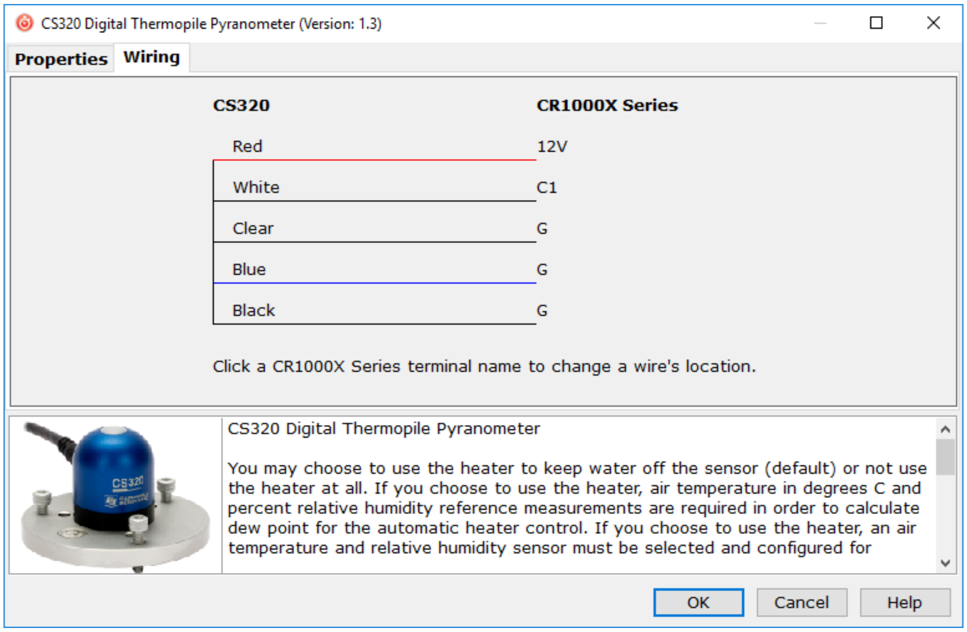
A video that describes data logger programming using Short Cut is available at: www.campbellsci.com/videos/cr1000x-datalogger-getting-started-program-part-3 ▶. Short Cut is an easy way to program your data logger to measure the sensor and assign data logger wiring terminals. Short Cut is available as a download on www.campbellsci.com. It is included in installations of LoggerNet, PC200W, PC400, or RTDAQ.

The following procedure also shows using Short Cut to program the CS320.

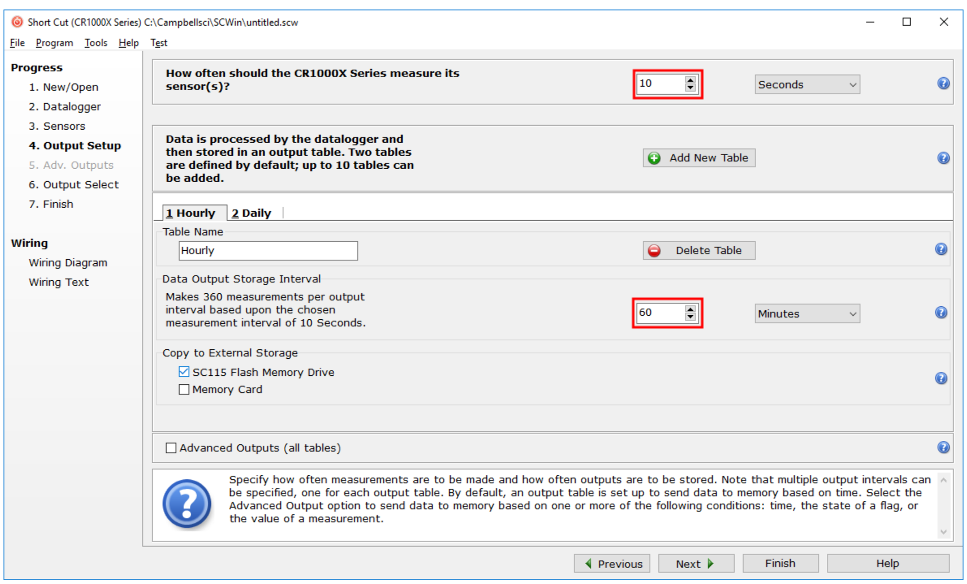
1. Open Short Cut and click **Create New Program**.
2. Double-click the data logger model.
3. In the **Available Sensors and Devices** box, type CS320 or find the sensor in the **Sensors** > **Meteorological** > **Solar Radiation** folder, and double-click **CS320 Digital Thermopile Pyranometer**. The flux density units defaults to **kW/m^2**. This can be changed by clicking the **Flux Density** box and selecting one of the other options. The total flux units defaults to **MJ/m^2**. This can be changed by clicking the **Total Flux** box and selection one of the other options. The default **SDI-12 Address** is 0. Enter the correct **SDI-12 Address** for the sensor if it has been changed from the factory-set default value. If not using the heater, uncheck the **Use internal heater to keep water off sensor** box. Otherwise, select the correct variable names for the reference temperature and relative humidity measurements.



4. Click the **Wiring** tab. Click **OK** after wiring the sensor.

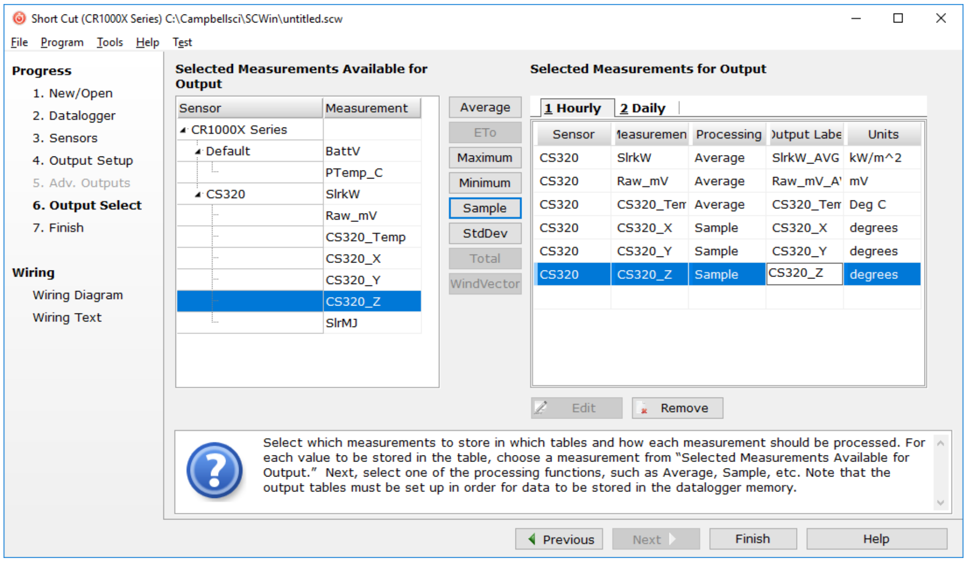


5. Repeat steps three and four for other sensors you want to measure. Click **Next**.
6. In **Output Setup**, type the scan rate, a **Table Name**, and **Data Output Storage Interval**. Click **Next**.



> **NOTE:**
> Because of the delays using SDI-12, Campbell Scientific recommends measurement scans of 10 seconds or more.

7. Select the output options.



8. Click **Finish** and save the program. Send the program to the data logger if the data logger is connected to the computer.
9. If the sensor is connected to the data logger, check the output of the sensor in the data display in LoggerNet, PC400, RTDAQ, or PC200W to make sure it is making reasonable measurements.

5. Overview

The CS320 is designed for continuous measurement of shortwave radiation from the sky. It consists of a thermopile detector, acrylic diffuser, heater, onboard level sensor, and signal processing circuitry mounted in an aluminum housing that is potted solid with no internal air space. These design features allow the CS320 to provide better spectral response than that of similarly priced silicon-cell pyranometers.

The internal heater keeps water (liquid and frozen) off the filter. Campbell Scientific recommends only powering the heater when frost or condensation is likely to occur because the heater increases power consumption and affects the thermal offset specification (Zero offset A).

The level sensor outputs X, Y, and Z-axis measurements that are useful for installation, diagnostics, and remote troubleshooting. Ideally, the X, Y, and Z measurements should be zero. Tilt in any direction changes the Z-axis measurement. If the Z-axis measurement is greater than 1.0 or less than -1.0, the CS320 needs to be leveled. With the appropriate data logger programming and telemetry commands, the data logger can automatically notify the user when the CS320 is no longer level, which can affect the accuracy of the global radiation measurements.

The CS320 has an SDI-12 output, where shortwave radiation is returned in digital format. Measurement of CS320 pyranometer requires a measurement device, typically a data logger, with SDI-12 functionality that includes the `M` or `C` command.

6. Specifications

Features:

- Thermopile sensor eliminates spectral errors associated with silicon-cell pyranometers
- Onboard sensor that automatically detects if the CS320 is level for installation, diagnostics, and remote troubleshooting
- Designed for long-term stability
- Dome shape sensor head allows dew and rain to run off
- Internal heater to reduce errors from dew, frost, rain, and snow
- SDI-12 digital output
- Detachable cable from sensor head for fast sensor swap / servicing
- Calibration data stored in sensor
- Factory calibrations traceable to secondary standard blackbody thermopile pyranometers traceable to the world radiation reference in Davos, Switzerland
- Compatible with Campbell Scientific CRBasic data loggers: CR200(X) series, CR300 series, CR6 series, CR800 series, CR1000, CR1000X series, CR3000, and CR5000

Calibration uncertainty:	± 2.6%
Measurement range:	0 to 2000 W m^{-2} (net shortwave irradiance)
Measurement repeatability:	< 1%
Long-term drift:	< 2% per year
Nonlinearity:	< 1%
Detector type:	Blackbody thermopile
Detector response time:	2 s
Field of view:	180°
Spectral range:	385 to 2105 nm (net shortwave radiation)
Directional (cosine) response:	< ±20 W m^{-2} up to solar zenith angles of 80°

Temperature response:	< 5% at –15 to 45 °C
Output:	SDI-12 version 1.4, 1200 bps
Operating temperature:	–50 to 50 °C
Relative humidity:	0 to 100%
Zero offset A:	8 W m^{-2}
Zero offset B:	< 5 W m^{-2}
Heater:	0.2 W (onboard)
Heater power requirements:	25 mA current drain at 12 VDC
Input voltage requirements:	6 to 24 VDC
Current drain:	5 mA (measurement), 3 mA (standby)
Uncertainty with daily total:	< 5%
Error due to clouds:	± 2%
Mechanical rating:	IP66/68
Diameter:	3.4 cm (1.4 in)
Height:	4.0 cm (1.6 in)
Weight:	~65 g (2.3 oz) (may vary due to potting)
Compliance:	View compliance documents at: www.campbellsci.com/cs320

7. Installation

If you are programming your data logger with Short Cut, skip Wiring (p. 9), and Programming (p. 9). Short Cut does this work for you. See QuickStart (p. 1), for a Short Cut tutorial.

7.1 Siting

The CS320 should be mounted such that no shadows or reflections are cast on it by the tripod/tower or other sensors. Mounting the CS320 on a crossarm can help avoid reflections from the tripod or tower mast. The sensor should be mounted with the cable pointing towards the nearest magnetic pole. For example, in the Northern Hemisphere, point the cable toward the North Pole.

Mounting height is not critical for the accuracy of the measurement. However, pyranometers mounted at heights of 3 m or less are easier to level and clean.

7.2 Mounting procedure

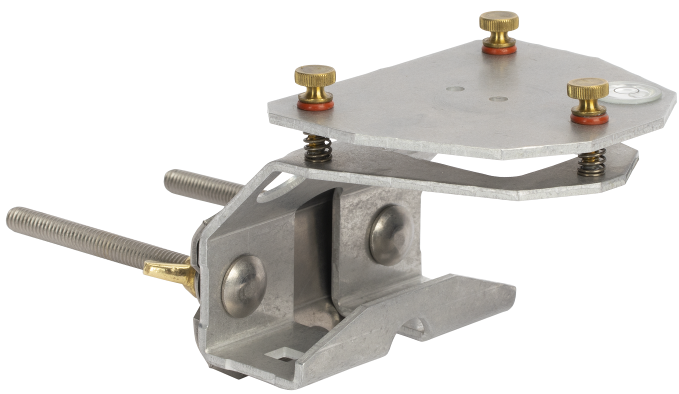
The CS320 mounts to a tripod or tower using the CM226 Solar Sensor Stand, which integrates leveling and mounting hardware into one mount.

> **NOTE:**
> You can also use a CM225 or 015ARM to mount the CS320 to a tripod or tower. However, a leveling base is required. The installation procedure for using the CM225 and 015ARM mounts is available in an older manual at www.campbellsci.com/old-manuals.

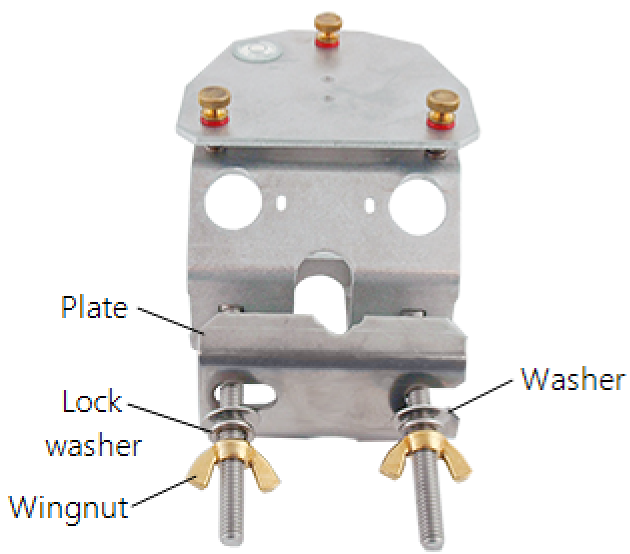
Tools required for installation on a tripod or tower:

- Tape measure
- UV-resistant cable ties
- Compass
- Step ladder

1. Mount the crossarm to the tripod or tower if using one.
2. Secure the CS320 to the CM226.



3. Place the screws, plate, washers, lock washers, and wing nuts in the side holes if using a vertical pipe or in the bottom holes if using a crossarm.



4. Place the vertical pipe or crossarm between the plate and bracket, then tighten the wing nuts until the lock washers are compressed.
5. Use your fingers to turn the leveling screws as required to bring the bubble of the bubble level within the ring.
6. Route the sensor cable along the underside of the crossarm to the tripod/tower, and to the instrument enclosure.
7. Secure the cable to the crossarm and mast using cable ties.
8. Remove the green cap after installing the sensor. Save this cap for shipping or storing the sensor.

7.3 Wiring

Connect the wires in the order shown in Table 7-1 (p. 9).

Table 7-1: Wire color, function, and data logger connection

Wire color	Wire function	Data logger connection
White	SDI-12 signal	**C**, **SDI-12**, or **U** configured for SDI-12[1]
Clear	Shield	⏚ (analog ground)
Red	Power	**12V**
Black	Power ground	**G**
Blue	Ground	⏚ (analog ground)

[1]**U** and **C** terminals are automatically configured by the measurement instruction.

If multiple SDI-12 sensors are connected to a data logger, Campbell Scientific recommends using separate terminals when possible. However, multiple SDI-12 sensors can connect to the same data logger control or **U** terminal. Each must have a unique SDI-12 address. Valid addresses are 0 through 9, a through z, and A through Z.

For the CR6 and CR1000X data loggers, triggering conflicts may occur when a companion terminal is used for a triggering instruction such as `TimerInput()`, `PulseCount()`, or `WaitDigTrig()`. For example, if the CS320 is connected to C3 on a CR1000X, C4 cannot be used in the `TimerInput()`, `PulseCount()`, or `WaitDigTrig()` instructions.

7.4 Programming

Short Cut is the best source for up-to-date programming code for Campbell Scientific data loggers. If your data acquisition requirements are simple, you can probably create and maintain a data logger program exclusively with Short Cut. If your data acquisition needs are more complex, the files that Short Cut creates are a great source for programming code to start a new program or add to an existing custom program.

> **NOTE:**
> Short Cut cannot edit programs after they are imported and edited in CRBasic Editor.

A Short Cut tutorial is available in QuickStart (p. 1). If you wish to import Short Cut code into CRBasic Editor to create or add to a customized program, follow the procedure in Importing Short Cut code into CRBasic Editor (p. 15). Programming basics for CRBasic data loggers are provided in the following section. Complete program examples for select CRBasic data loggers can be found in Example programs (p. 16).

7.4.1 SDI-12 programming

The `SDI12Recorder()` instruction is used to measure a CS320. This instruction sends a request to the sensor to make a measurement and then retrieves the measurement from the sensor. See SDI-12 measurements (p. 11) for more information.

For most data loggers, the `SDI12Recorder()` instruction has the following syntax:

```
SDI12Recorder(Destination, SDIPort, SDIAddress, "SDICommand", Multiplier,
Offset, FillNAN, WaitonTimeout)
```

For the `SDIAddress`, alphabetical characters need to be enclosed in quotes (for example, "A"). Also enclose the `SDICommand` in quotes as shown. The `Destination` parameter must be an array. The required number of values in the array depends on the command (see Table 8-1 (p. 11)).

`FillNAN` and `WaitonTimeout` are optional parameters (refer to CRBasic Help for more information).

7.4.2 Total flux density

The total flux density, in kJ m^{-2}, may be calculated from the calibrated solar radiation measurement using this expression:

$$FluxDensity = SolarRad \cdot Scan\ Rate \cdot 10^{-6}$$

Because the scan rate is part the total flux density equation, the scan rate often is entered as a constant at the beginning of the CRBasic program. Also, when totalizing the measurement, the IEEE4 or long data format is used to avoid over ranging on sunny days. Refer to Example programs (p. 16) for more information.

8. Operation

The CS320 is a thermopile pyranometer.Thermopile pyranometers use a series of thermoelectric junctions to provide a signal of several µV/W/m^2 proportional to the temperature difference between a black absorbing surface and a reference. The reference may be either a white reflective surface or the internal portion of the sensor base. The black surface of the thermopile uniformly absorbs solar radiation across the solar spectrum.

The solar spectrum is the range of wavelengths of the light given off by the sun. Blue, white, yellow, and red stars each have different temperatures and therefore different solar spectrums.

Our yellow sun outputs radiation in wavelengths from 0.15 to 4.0 µm. The thermopile pyranometer accurately captures the global solar radiation of the sun because its special black absorptive surface uniformly responds to most of the solar-spectrum energy.

The advantages of thermopile pyranometers relate to their broad usage and accuracy. The black surface of the CS320 thermopile uniformly absorbs solar radiation across the shortwave solar spectrum from 385 to 2105 nm.

8.1 SDI-12 measurements

The CS320 responds to the `M!`, `M1!`, `M2!`, `M3!`, `M4!`, `C!`, `C1!`, `C2!`, `C3!`, `C4!`, and `?!` SDI-12 commands. CS320 SDI-12 commands (p. 11) shows the values returned for each of these commands. When using an `M!`, `M1!`, `M2!`, `M3!`, or `M4!` command, the data logger waits for the time specified by the sensor, sends the `D!` command, pauses its operation, and waits until either it receives the data from the sensor or the sensor timeout expires. If the data logger receives no response, it will send the command a total of three times, with three retries for each attempt, or until a response is received.

A `C!`, `C1!`, `C2!`, `C3!`, or `C4!` command follows the same pattern as an `M!`, `M1!`, `M2!`, `M3!`, or `M4!` command with the exception that it does not require the data logger to pause its operation until the values are ready. Rather, the data logger retrieves the data with the `D!` command on the next pass through the program. Another measurement request is then sent so that data are ready on the next scan.

NOTE:
SDI-12 sensor support (p. 21) describes the SDI-12 commands. Additional SDI-12 information is available at www.sdi-12.org.

Table 8-1: CS320 SDI-12 commands

SDI-12 command[1]	Values Returned or Function	Units
a`M!` or *a*`C!`	Calibrated solar radiation	W m^{-2}
a`M1!` or *a*`C1!`	Raw detector millivolts	mV
a`M2!` or *a*`C2!`	Sensor temperature	°C
a`M3!` or *a*`C3!`	1. X-axis 2. Y-axis 3. Z-axis	1. ° 2. ° 3. °

Table 8-1: CS320 SDI-12 commands		
SDI-12 command[1]	Values Returned or Function	Units
*a*M4! or *a*C4!	1. Solar radiation 2. Raw millivolts 3. Sensor temperature 4. X-axis value 5. Y-axis value 6. Z-axis value	1. W/m^2 2. mV 3. ° C 4. ° 5. ° 6. °
*a*XHON!	Turn heater on	
*a*XHOFF!	Turn heater off	
?!	SDI-12 address	
[1]a is the sensor address.		

8.2 Measurements at fast scan rates

Using the `SlowSequence` function allows the SDI-12 instruction to run as a background process, causing minimum interference to other measurements that use the analog hardware. Measuring the CS320 in a `SlowSequence` section of the program allows faster programs to run as the main scan. However, if the data logger is too busy to complete all of its tasks, some slow sequence commands may be skipped resulting in NANs (not a number) instead of measurements.

8.3 Heater control

Use the **XHON!** SDI-12 command to turn the heater on and the **XHOFF!** SDI-12 command to turn the heater off.

Campbell Scientific recommends only powering the heater when frost or condensation is likely to occur. The most convenient method for doing this is to have the data logger program turn the heater on and off based on air temperature measurements and dewpoint calculations. CRBasic Example 2 (p. 18), provides a CR6 program that automatically controls the heater.

8.4 Long cables

The SDI-12 standard specifies the maximum total cable length to be 61 m (200 ft). Digital data transfer eliminates offset errors due to cable lengths. However, digital communications can break down when cables are too long, resulting in either no response from the sensor or corrupted readings.

9. Troubleshooting and maintenance

NOTE:
All factory repairs and recalibrations require a returned material authorization (RMA) and completion of the "Declaration of Hazardous Material and Decontamination" form. Refer to the Assistance (p. ii) page at the beginning of this manual for more information.

9.1 Maintenance and calibration

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 (for example, 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 acrylic diffuser.

CAUTION:
Handle the sensor carefully when cleaning. Be careful not to scratch the surface of the sensor.

The *Clear Sky Calculator* (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 ±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, enter 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, contact Campbell Scientific to discuss test results and possible return of sensor(s). Refer to the Assistance (p. ii) page at the beginning of this document for the process of returning the pyranometer to Campbell Scientific for recalibration.

9.2 Troubleshooting

Table 9-1 (p. 14) provides symptoms and solutions.

Table 9-1: Symptoms and solutions

Symptom	Solution
Real-time (Public table) radiation values of –9999, NAN, or around 0	1. Check that the sensor is wired to the control port specified by the `SDI12Recorder()` instruction. Verify the red wire is connected to a **12V** terminal. 2. Check the voltage to the sensor with a digital voltmeter. If a switched **12V** terminal is used, temporarily connect the red wire to a **12V** terminal (non-switched) for test purposes. 3. Verify the sensor SDI-12 address matches the address entered for the `SDI12Recorder()` instruction. The default address is 0. The address can be verified or changed with the commands described in SDI-12 command basics (p. 21).
Incorrect solar radiation	1. Make sure the green protective cap has been removed. 2. Make sure the top surface of the sensor head is clean and that the sensor is properly leveled.

For more information refer to:

www.campbellsci.com/videos/sdi12-sensors-transparent-mode

www.campbellsci.com/videos/sdi12-sensors-watch-or-sniffer-mode

Appendix A. Importing Short Cut code into CRBasic Editor

Short Cut creates a .DEF file that contains wiring information and a program file that can be imported into the CRBasic Editor. By default, these files reside in the C:\campbellsci\SCWin folder.

Import Short Cut program file and wiring information into CRBasic Editor:

1. Create the Short Cut program following the procedure in QuickStart (p. 1). After saving the Short Cut program, click the **Advanced** tab then the **CRBasic Editor** button. A program file with a generic name will open in CRBasic. Provide a meaningful name and save the CRBasic program. This program can now be edited for additional refinement.

   > **NOTE:**
   > Once the file is edited with CRBasic Editor, Short Cut can no longer be used to edit the program it created.

2. To add the Short Cut wiring information into the new CRBasic program, open the .DEF file located in the C:\campbellsci\SCWin folder, and copy the wiring information, which is at the beginning of the .DEF file.
3. Go into the CRBasic program and paste the wiring information into it.
4. In the CRBasic program, highlight the wiring information, right-click, and select **Comment Block**. This adds an apostrophe (') to the beginning of each of the highlighted lines, which instructs the data logger compiler to ignore those lines when compiling. The **Comment Block** feature is demonstrated at about 5:10 in the CRBasic | Features video.

Appendix B. Example programs

Table B-1 (p. 16) provides the wiring for the example programs. Both example programs use the `M4!` command to return solar radiation (W m^{-2}), raw millivolt value (mV), sensor temperature (°C), and X, Y, and Z-axis values (°). The programs also calculate the daily total flux (MJ).

The CR6 example program also controls the heater based on air temperature measurements, dewpoint calculations, and battery voltage measurements. The HygroVUE™10 Air Temperature and Relative Humidity Probe provides the measurements used in the dewpoint calculation.

Table B-1: Wiring for example programs

Wire color	Wire function	CR1000X connections	CR6 connections
CS320 Solar Radiation Sensor			
White	SDI-12 signal	C1	C3
Clear	Shield	⏚	⏚
Red	Power	12V	12V
Black	Power ground	G	G
Blue	Ground	⏚	⏚
HygroVUE10 Temperature and Relative Humidity Sensor			
White	SDI-12 signal	N/A	C1
Clear	Shield	N/A	⏚
Brown	Power	N/A	12V
Black	Power ground	N/A	G
Blue	Ground	N/A	⏚

CRBasic Example 1: CR1000X program using the CS320 M4! command

```
'Program scan rate, in seconds, can be changed here and changes
'will automatically roll into the multiplier for megajoules.
'Must be defined as a constant.
Const SCANRATE = 10

'Declare Variables and Units
Public CS320(6)
Public SlrMJ

Alias CS320(1)=SlrRad_W
Alias CS320(2)=Raw_mV
Alias CS320(3)=SensorTemp
Alias CS320(4)=X_orient
Alias CS320(5)=Y_orient
Alias CS320(6)=Z_orient

Units SlrRad_W=W/M^2
Units Raw_mV=mV
Units SensorTemp=C
Units X_orient=deg
Units Y_orient=deg
Units Z_orient=deg
Units SlrMJ=MJ

'Define Data Tables
DataTable(Hourly,True,-1)
  DataInterval(0,60,Min,10)
  Average(1,SlrRad_W,FP2,False)
  Average(1,Raw_mV,FP2,False)
  Average(1,SensorTemp,FP2,False)
  Sample(1,X_orient,FP2)
  Sample(1,Y_orient,FP2)
  Sample(1,Z_orient,FP2)
EndTable

DataTable(Daily,True,-1)
  DataInterval(0,1440,Min,10)
  Totalize (1,SlrMJ,IEEE4,False)
EndTable

'Main Program
BeginProg
  'Main Scan
  Scan(SCANRATE,Sec,2,0)
    SDI12Recorder(CS320(),C1,"0","M4!",1,0,-1)

    If SlrRad_W < 0 Then SlrRad_W = 0
```

CRBasic Example 1: CR1000X program using the CS320 M4! command

```
    SlrMJ = SlrRad_W * SCANRATE * 1E-6

    CallTable Hourly
    CallTable Daily
  NextScan
EndProg
```

CRBasic Example 2: CR6 program controlling the CS320 heater

```
'Program scan rate, in seconds, can be changed here and changes
'will automatically roll into the multiplier for megajoules.
'Must be defined as a constant.
Const SCANRATE = 10

'Data logger internal measurements.
Public BattV : Units BattV = Volts 'Battery voltage
Public PTemp_C : Units PTemp_C = Deg C 'Data logger panel temp.

'HygroVUE10 temperature/relative humidity variables.
Public TRHData(2)

'Dewpoint calculation variable.
Public DewPtC : Units DewPtC = Deg C 'Dewpoint temperature
Public SlrMJ : Units SlrMJ = MJ/m^2 'Total solar flux
Public HtrCntrl As Boolean 'Flag controls heater state.

'CS320 heated pyranometer variables.
Public CS320(6)
Dim AirDewDif 'Stores air temp. & dewpoint differences
Dim Htr

Alias TRHData(1)=AirTempC : Units AirTempC = Deg C 'Air temp.
Alias TRHData(2)=RH : Units RH = % 'Relative humidity
Alias CS320(1)= SlrW : Units SlrW = W/m^2 'Solar flux density
Alias CS320(2)= Raw_mV : Units Raw_mV = mV
Alias CS320(3)= CS320_Temp : Units CS320_Temp = Deg C
Alias CS320(4)= CS320_X : Units CS320_X = Deg
Alias CS320(5)= CS320_Y : Units CS320_Y = Deg
Alias CS320(6)= CS320_Z : Units CS320_Z = Deg

DataTable(Hourly,True,-1)
  DataInterval(0,60,Min,10)
  Average (1,AirTempC,FP2,False)
  Sample (1,RH,FP2)
  Average (1,DewPtC,FP2,False)
```

CRBasic Example 2: CR6 program controlling the CS320 heater

```
  Average(1,SlrW,FP2,False)
EndTable

DataTable(Daily,True,-1)
  DataInterval(0,1440,Min,10)
  Minimum (1,AirTempC,FP2,False,True)
  Maximum (1,AirTempC,FP2,False,True)
  Minimum (1,RH,FP2,False,True)
  Maximum (1,RH,FP2,False,True)
  Minimum (1,DewPtC,FP2,False,True)
  Maximum (1,DewPtC,FP2,False,True)
  Totalize(1,SlrMJ,IEEE4,False) 'IEEE4 to not overrun on sunny days
  Histogram (HtrCntrl * -1,FP2,False,2,000,1,0,1)
  FieldNames ("FracHtrTimeOff,FracHtrTimeOn")
  Minimum (1,BattV,FP2,False,False)
  Maximum (1,BattV,FP2,False,False)
  Minimum (1,PTemp_C,FP2,False,False)
  Maximum (1,PTemp_C,FP2,False,False)
  Average (1,CS320_X,FP2,False)
  Average (1,CS320_Y,FP2,False)
  Average (1,CS320_Z,FP2,False)
EndTable

'Main Program
BeginProg
  'Main Scan
  Scan(SCANRATE,Sec,2,0)
    'Default Data logger Battery Voltage measurement 'BattV'
    Battery(BattV)
    'Default Wiring Panel Temperature measurement 'PTemp_C'
    PanelTemp(PTemp_C,_60Hz)

    'HygroVUE10 Temperature and RH measurements
    'AirTempC and RH
    SDI12Recorder(TRHData(),C1,"0","M!",1,0,-1)
    If RH>100 AND RH<103 Then RH=100
    'Dewpoint calculation, DewPtC
    DewPoint(DewPtC,AirTempC,RH)
    If DewPtC>AirTempC OR DewPtC=NAN Then DewPtC=AirTempC

    'CS320 Pyranometer measurements: SlrMJ and SlrW
    SDI12Recorder (CS320(),C3,0,"M4!",1.0,0)
    SlrMJ = SlrW * SCANRATE * 1E-6

    'CS320 Heater Control
    'Calculate difference between CS320 temperature and dewpoint.
    AirDewDif = CS320_Temp - DewPtC
```

CRBasic Example 2: CR6 program controlling the CS320 heater

```
    'Heater operates only if battery voltage is > 11.7 VDC
    If BattV >= 11.7 Then
      'Do the following if heater is off.
      If HtrCntrl = False Then
        'Turn heater on regardless of dewpoint if air temp. is < 2°C.
        If AirTempC <= 2 Then
          HtrCntrl = True
        Else
          'Turn heater on if air temp. is above 2°C and sensor temp.
          'and dewpoint difference is < or = 2°C.
          If AirDewDif <= 2 Then HtrCntrl = True
        EndIf
      Else
        'If heater is already on, and air temp. is greater than
        '3°C and air temp. and dewpoint difference is 3°C,
        'then shut the heater off.
        If (AirTempC > 3) AND (AirDewDif >= 3) Then HtrCntrl = False
      EndIf
    Else
      'Shut heater off if battery voltage is less than 11.7 VDC
      HtrCntrl = False
    EndIf

    'CS320 heater is SDI-12 controlled by the Boolean variable HtrCntrl.
    If HtrCntrl = True Then SDI12Recorder (Htr,C3,0,"XHON!",1.0,0)
    If HtrCntrl = False Then SDI12Recorder (Htr,C3,0,"XHOFF!",1.0,0)

    'Call Data Tables and Store Data
    CallTable Hourly
    CallTable Daily
  NextScan
EndProg
```

Appendix C. SDI-12 sensor support

SDI-12, Serial Data Interface at 1200 baud, is a protocol developed to simplify sensor and data logger compatibility. Only three wires are necessary — serial data, ground, and 12 V. With unique addresses, multiple SDI-12 sensors can connect to a single SDI-12 terminal on a Campbell Scientific data logger.

This appendix discusses the structure of SDI-12 commands and the process of querying SDI-12 sensors. For more detailed information, refer to version 1.4 of the SDI-12 protocol, available at www.sdi-12.org.

For additional information, refer to the SDI-12 Sensors | Transparent Mode and SDI-12 Sensors | Watch or Sniffer Mode videos.

C.1 SDI-12 command basics

SDI-12 commands have three components:

- **Sensor address (a)** – a single character and the first character of the command. Use the default address of zero (0) unless multiple sensors are connected to the same port.
- **Command body** – an upper case letter (the "command"), optionally followed by one or more alphanumeric qualifiers.
- **Command termination (!)** – an exclamation mark.

An active sensor responds to each command. Responses have several standard forms and always terminate with <CR><LF> (carriage return and line feed). Standard SDI-12 commands are listed in Table C-1 (p. 21).

Table C-1: Campbell Scientific sensor SDI-12 command and response set

Name	Command	Response[1]
Acknowledge Active	`a!`	a<CR><LF>
Send Identification	`aI!`	allccccccccmmmmmmvvvxxx...xx <CR><LF>
Start Verification	`aV!`	atttn <CR><LF>
Address Query	`?!`	a<CR><LF>

Table C-1: Campbell Scientific sensor SDI-12 command and response set

Name	Command	Response[1]
Change Address	`aAb!`	b<CR><LF>
Start Measurement	`aM!` `aM1!...aM9!`	atttn<CR><LF>
Start Measurement and Request CRC	`aMC!` `aMC1!...aMC9!`	atttn <CR><LF>
Start Concurrent Measurement	`aC!` `aC1!...aC9!`	atttnn<CR><LF>
Start Concurrent Measurement and Request CRC	`aCC!` `aCC1!...aCC9!`	atttnn<CR><LF>
Send Data	`aD0!...aD9!`	a<values><CR><LF> or a<values><CRC><CR><LF>
Continuous Measurement	`aR0!...aR9!`	a<values><CR><LF>
Continuous Measurement and Request CRC	`aRC0!...aRC9!`	a<values><CRC><CR><LF>
Extended Commands	`aXNNN!`	a<values><CR><LF>

[1] Information on each of these commands is given in the following sections.

C.2 Acknowledge active command (a!)

The Acknowledge Active command (`a!`) is used to test a sensor on the SDI-12 bus. An active sensor responds with its address.

C.3 Send identification command (aI!)

Sensor identifiers are requested by issuing command `aI!`. The reply is defined by the sensor manufacturer but usually includes the sensor address, SDI-12 version, manufacturer's name, and sensor model information. Serial number or other sensor specific information may also be included.

`aI!`	allccccccccmmmmmmvvvxxx...xx<CR><LF>
a	Sensor SDI-12 address
ll	SDI-12 version number (indicates compatibility)

cccccccc	8-character vendor identification
mmmmmm	6 characters specifying the sensor model
vvv	3 characters specifying the sensor version (operating system)
xxx…xx	Up to 13 optional characters used for a serial number or other specific sensor information that is not relevant for operation of the data logger
<CR><LF>	Terminates the response
Source: *SDI-12: A Serial-Digital Interface Standard for Microprocessor-Based Sensors* (see References).	

C.4 Start verification command (aV!)

The response to a Start Verification command can include hardware diagnostics, but like the `aI!` command, the response is not standardized.

Command: `aV!`

Response: *atttn<CR><LF>*

a = sensor address

ttt = time, in seconds, until verification information is available

n = the number of values to be returned when one or more subsequent `D!` commands are issued

C.5 Address query command (?!)

Command `?!` requests the address of the connected sensor. The sensor replies to the query with the address, *a*. This command should only be used with one sensor on the SDI-12 bus at a time.

C.6 Change address command (aAb!)

Multiple SDI-12 sensors can connect to a single SDI-12 terminal on a data logger. Each device on a single terminal must have a unique address.

A sensor address is changed with command `aAb!`, where *a* is the current address and *b* is the new address. For example, to change an address from *0* to *2*, the command is `0A2!`. The sensor responds with the new address *b*, which in this case is 2.

> **NOTE:**
> Only one sensor should be connected to a particular terminal at a time when changing addresses.

C.7 Start measurement commands (aM!)

A measurement is initiated with the **M!** command. The response to each command has the form *atttn<CR><LF>*, where

a = sensor address

ttt = time, in seconds, until measurement data is available. When the data is ready, the sensor notifies the data logger, and the data logger begins issuing **D** commands.

n = the number of values returned when one or more subsequent **D** commands are issued. For the **aM!** command, n is an integer from 0 to 9.

When the **aM!** is issued, the data logger pauses its operation and waits until either it receives the data from the sensor or the time, *ttt*, expires. Depending on the scan interval of the data logger program and the response time of the sensor, this may cause skipped scans to occur. In this case make sure your scan interval is longer than the longest measurement time (*ttt*).

Table C-2: Example aM! sequence	
0M!	The data logger makes a request to sensor 0 to start a measurement.
00352<CR><LF>	Sensor 0 immediately indicates that it will return two values within the next 35 seconds.
0<CR><LF>	Within 35 seconds, sensor 0 indicates that it has completed the measurement by sending a service request to the data logger.
0D0!	The data logger immediately issues the first **D** command to collect data from the sensor.
0+.859+3.54<CR><LF>	The sensor immediately responds with the sensor address and the two values.

C.8 Start concurrent measurement commands (aC!)

A concurrent measurement (**aC!**) command follows the same pattern as the **aM!** command with the exception that it does not require the data logger to pause its operation, and other SDI-12 sensors may take measurements at the same time. The sensor will not issue a service request to notify the data logger that the measurement is complete. The data logger will issue the **aD0!** command during the next scan after the measurement time reported by the sensor has expired. To use this command, the scan interval should be 10 seconds or less. The response to each command has the form *atttn<CR><LF>*, where *a* = the sensor address

ttt = time, in seconds, until the measurement data is available

nn = the number of values to be returned when one or more subsequent **D** commands are issued.

See the following example. A data logger has three sensors wired into terminal **C1**. The sensors are addresses X, Y, and Z. The data logger will issue the following commands and receive the following responses:

Table C-3: Example aC! sequence	
XC!	The data logger makes a request to sensor X to start a concurrent measurement.
X03005<CR><LF>	Sensor X immediately indicates that it will have 5 (05) values ready for collection within the next 30 (030) seconds.
YC!	The data logger makes a request to sensor Y to start a concurrent measurement.
Y04006<CR><LF>	Sensor Y immediately indicates that it will have 6 (06) values ready for collection within the next 40 (040) seconds.
ZC!	The data logger makes a request to sensor Z to start a concurrent measurement.
Z02010<CR><LF>	Sensor Z immediately indicates that it will have 10 values ready for collection within the next 20 (020) seconds.
ZD0!	After 20 seconds have passed, the data logger starts the process of collecting the data by issuing the first **D** command to sensor Z.
Z+1+2+3+4+5+6+7+8+9+10<CR><LF>	Sensor Z immediately responds with the sensor address and the 10 values.
XD0!	10 seconds later, after a total of 30 seconds have passed, the data logger starts the process of data from sensor X by issuing the first **D** command.
X+1+2+3+4+5<CR><LF>	The sensor immediately responds with the sensor address and the 5 values.

Table C-3: Example aC! sequence	
YD0!	Ten seconds later, after a total of 40 seconds have passed, the data logger starts the process of data from sensor Y by issuing the first **D** command.
Y+1+2+3+4+5+6<CR><LF>	The sensor immediately responds with the sensor address and the 6 values.

C.9 Stopping a measurement command

A measurement command (`M!`) is stopped if it detects a break signal. A break signal is sent by the data logger before most commands.

A concurrent measurement command (`C!`) is aborted when another valid command is sent to the sensor before the measurement time has elapsed.

C.10 Send data command (aD0! … aD9!)

The Send Data command requests data from the sensor. It is issued automatically with every type of measurement command (**aM!**, **aMC!**, **aC!**, **aCC!**). When the measurement command is a**M!** or a**MC!**, the data logger issues the **aD0!** command once a service request has been received from the sensor. When the data logger is issuing concurrent commands (**aC!** or **aCC!**), the Send Data command is issued after the required time has elapsed (no service request will be sent by the sensor). In transparent mode (SDI-12 transparent mode (p. 27)), the user asserts this command to obtain data.

Depending on the type of data returned and the number of values a sensor returns, the data logger may need to issue **aD0!** up to **aD9!** to retrieve all data. A sensor may return up to 35 characters of data in response to a **D** command that follows an **M!** or **MC!** command. A sensor may return up to 75 characters of data in response to a **D** command that follows a **C!** or **CC!** command.

Command: **aD0!** (**aD1!** … **aD9!**)

Response: *a<values><CR><LF>* or *a<values><CRC><CR><LF>*

where:

a = the sensor address

<values> = values returned with a polarity sign (+ or –)

<CR><LF> = terminates the response

<CRC> = 16-bit CRC code appended if data was requested with a**MC!** or **aCC!**.

C.11 Extended commands

Many sensors support extended SDI-12 commands. An extended command is specific to a make of sensor and tells the sensor to perform a specific task. They have the following structure. Responses vary from unit to unit. See the sensor manual for specifics.

Command: `aXNNNN!`

The command will start with the sensor address (**a**), followed by an **X**, then a set of optional letters, and terminate with an exclamation point.

Response: *a<optional values><CR><LF>*

The response will start with the sensor address and end with a carriage return/line feed.

C.12 SDI-12 transparent mode

System operators can manually interrogate and enter settings in probes using transparent mode. Transparent mode is useful in troubleshooting SDI-12 systems because it allows direct communication with probes. Data logger security may need to be unlocked before activating the transparent mode.

Transparent mode is entered while the PC is communicating with the data logger through a terminal emulator program. It is accessed through Campbell Scientific data logger support software or other terminal emulator programs. Data logger keyboards and displays cannot be used.

The terminal emulator is accessed by navigating to the **Datalogger** list in PC200W, the **Tools** list in PC400, or the **Datalogger** list in the **Connect** screen of LoggerNet.

Watch the video: SDI-12 Sensors | Transparent Mode.

The following examples show how to enter transparent mode and change the SDI-12 address of an SDI-12 sensor. The steps shown in Changing an SDI-12 address (p. 27) are used with most Campbell Scientific data loggers. Changing an SDI-12 address — CR200(X) Series (p. 29) lists the steps used for CR200(X)-series data loggers.

C.12.1 Changing an SDI-12 address

The example below was done with a CR1000, but the steps are only slightly different for CR1000X-series, CR300-series, CR6-series, CR800-series, and CR3000 data loggers. For CR200(X)-series data loggers, see Changing an SDI-12 address — CR200(X) Series (p. 29).

1. Connect an SDI-12 sensor to the CR1000.
2. In **LoggerNet Connect**, under **Datalogger**, click **Terminal Emulator**. The terminal emulator window opens.
3. Under **Select Device**, located in the lower left side of the window, select the **CR1000** station.
4. Click **Open Terminal**.
5. Select **All Caps Mode**.
6. Press Enter until the data logger responds with the **CR1000>** prompt.
7. Type **SDI12** and press Enter.
8. At the **Select SDI12 Port** prompt, type the number corresponding to the control port where the sensor is connected and press Enter. The response **Entering SDI12 Terminal** indicates that the sensor is ready to accept SDI-12 commands.
9. To query the sensor for its current SDI-12 address, type **?!** and press Enter. The sensor responds with its SDI-12 address. If no characters are typed within 60 seconds, the mode is exited. In that case, simply type **SDI12** again, press Enter, and type the correct control port number when prompted.
10. To change the SDI-12 address, type **aAb!**, where **a** is the current address from the above step and **b** is the new address (see FIGURE C-1 (p. 29). Press Enter. The sensor changes its address and responds with the new address.
11. To exit SDI-12 transparent mode, click **Close Terminal**.

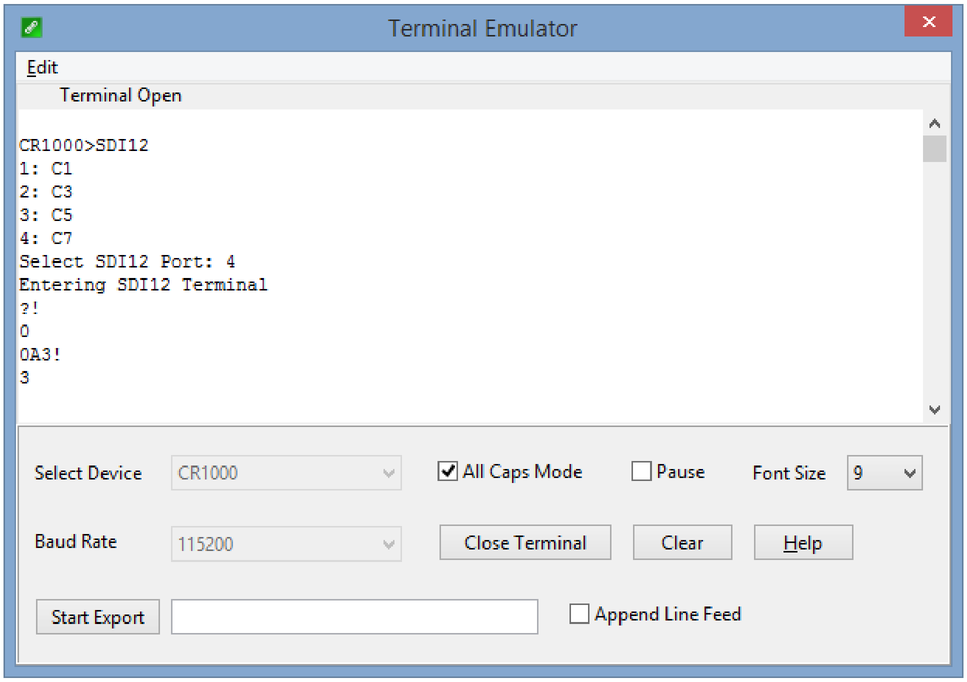


FIGURE C-1. CR1000 example of using the SDI-12 transparent mode to change the SDI-12 address from 0 to 3. Sensor is connected to control port 1.

C.12.2 Changing an SDI-12 address — CR200(X) Series

1. Connect a single SDI-12 sensor to the CR200(X).
2. In **LoggerNet Connect**, under **Datalogger**, click **Terminal Emulator**. The terminal emulator window opens.
3. Under **Select Device**, located in the lower left side of the window, select the **CR200Series** station.
4. Click **Open Terminal**.
5. Select **All Caps Mode**.
6. Press Enter until the data logger responds with the **CR2XX>** prompt.
7. Type **SDI12** and press Enter.
8. The response **SDI12>** indicates that the sensor is ready to accept SDI-12 commands.
9. To query the sensor for its current SDI-12 address, type **?!** and press Enter. The sensor responds with its SDI-12 address. If no characters are typed within 60 seconds, the mode is exited. In that case, simply type **SDI12** again and press Enter.

10. To change the SDI-12 address, type **aAb!**, where **a** is the current address from the above step and **b** is the new address (see FIGURE C-2 (p. 30)). Press Enter. The sensor changes its address and responds with the new address.
11. To exit SDI-12 transparent mode, click **Close Terminal**.

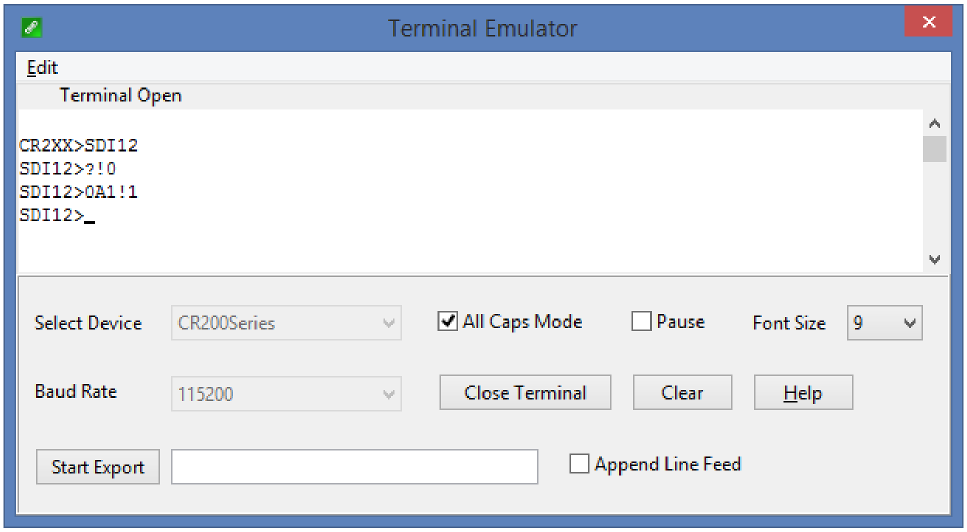


FIGURE C-2. CR200(X) example of using the SDI-12 transparent mode to change the SDI-12 address from 0 to 1

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