INSTRUCTION MANUAL

# NR01 Four-Component Net Radiation Sensor

Revision: 10/16

# *Limited Warranty*

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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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# NR01 Four-Component Net Radiation Sensor

## 1. Introduction

The NR01, manufactured by Hukseflux, is a research-grade net radiometer that measures the energy balance between incoming short-wave and long-wave infrared radiation versus surface-reflected short-wave and outgoing long-wave infrared radiation. Our dataloggers measure the NR01's output and control its internal heater. This net radiometer offers a professional solution for scientific-grade energy balance studies. The NR01 is robust and requires only limited maintenance.

**NOTE** This manual provides information only for CRBasic dataloggers. It is also compatible with most of our retired Edlog dataloggers. For Edlog datalogger support, see an older manual at *www.campbellsci.com/old-manuals* or contact a Campbell Scientific application engineer for assistance.

## 2. Precautions

- READ AND UNDERSTAND the *Safety* 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, consult with a Campbell Scientific application engineer.
- Although the NR01 is rugged, it should be handled as a precision scientific instrument.
- Warning: The sensor has two cables with similar color schemes. It is important to make sure you identify cable 1 and cable 2 correctly, especially before connecting any source of power such as to the heater. Failure to do so may damage the sensor.

## 3. Initial Inspection

- Upon receipt of the NR01, inspect the packaging and contents for damage. File damage claims with the shipping company.
- Each NR01 is shipped with a *Certificate of Calibration* that provides the sensor serial number and sensitivity for each of the four component sensors. Cross check this serial number against the serial number on your NR01 to ensure that the given sensitivity values correspond to your sensor.

# 4. Overview

The NR01 is a four-component net-radiometer consisting of two pyranometers of type SR01, two pyrgeometers of type IR01, a heater, and a PT100 temperature sensor. The pyranometer measures solar radiation (short wave or SW) and the pyrgeometer measures far infrared (long wave or LW) radiation. LW radiation is mainly present in the 4500 to 50000 nm region, while SW is mainly present in the 300 to 3000 nm region (see FIGURE 4-1).

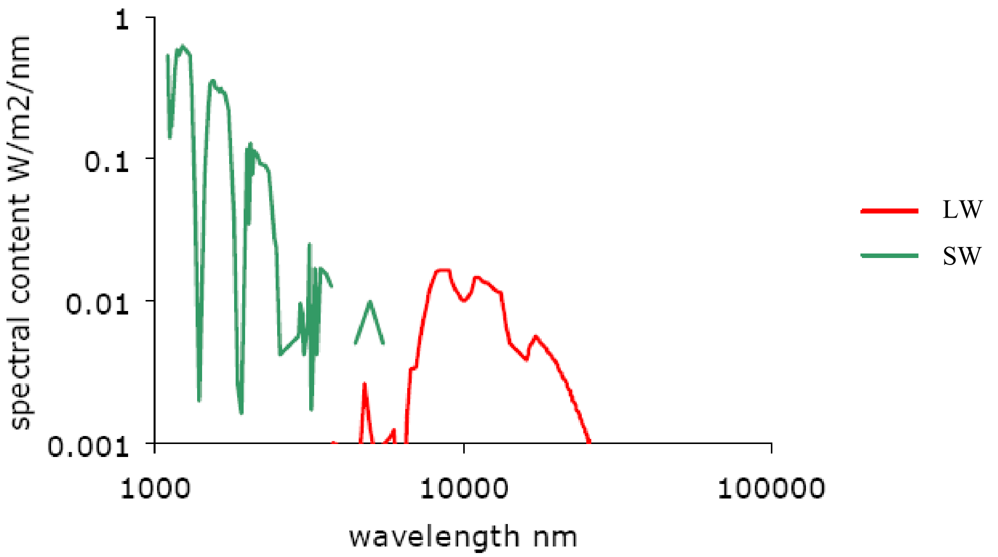


*FIGURE 4-1. Atmospheric Radiation as a Function of Wavelength*

The PT100 temperature sensor is included in the connection body of the pyrgeometers for calculation of the sky and surface temperature. The heater is included in the pyrgeometers' connection body, and is used to prevent dew.

Measurement of the separate components of the net radiation is useful because it:

- Enhances accuracy by having separately calibrated instruments (similar accuracy cannot be attained with sensors with single outputs or dual outputs). Single-output or dual-output instruments will always suffer from instrument asymmetry or from errors due to sensitivity differences for LW and SW radiation.

- Provides more detailed information than sensors with single or dual outputs (e.g., albedo of the ground, cloud condition).

- Allows more thorough quality assurance of the instrument data (compared to sensors with single or dual outputs). Quality assurance with four-component radiometers is done by analyzing trends in $SW_{in}$ absolute signal, SW albedo, correlation of $SW_{in}$ and $LW_{in}$, SW night time signals, and correlation $LW_{out}$ and surface temperature.

The NR01 measures the four separate components of the surface radiation balance. Working completely passive, using thermopile sensors, the NR01 generates four small output voltages proportional to the incoming and outgoing SW and LW fluxes; $SW_{in}$ or global solar radiation, $SW_{out}$ or reflected solar radiation, $LW_{in}$ or infrared emitted by the sky and $LW_{out}$ or infrared emitted by the ground surface. From these also parameter like SW albedo, sky temperature, (ground) surface temperature and off course net radiation (net value of all SW and LW fluxes) can be calculated.

The NR01 requires leveling; a two-axis leveling facility is incorporated in the design. See Section 6, *Installation (p. 7)*.

The NR01 is supplied with four separate instrument sensitivities. To calculate the radiation level, the sensor output voltage, U, must be divided by the sensor sensitivity; a constant, E, that is supplied with each individual instrument:

$$\Phi = SW_{in} = U_{pyrano,\ up} / E_{pyrano,\ up}$$

# 5. Specifications

FIGURE 5-1 shows some dimensions. TABLE 5-1, TABLE 5-2, and TABLE 5-3 provide the general, pyranometer, and pyrgeometer specifications, respectively.

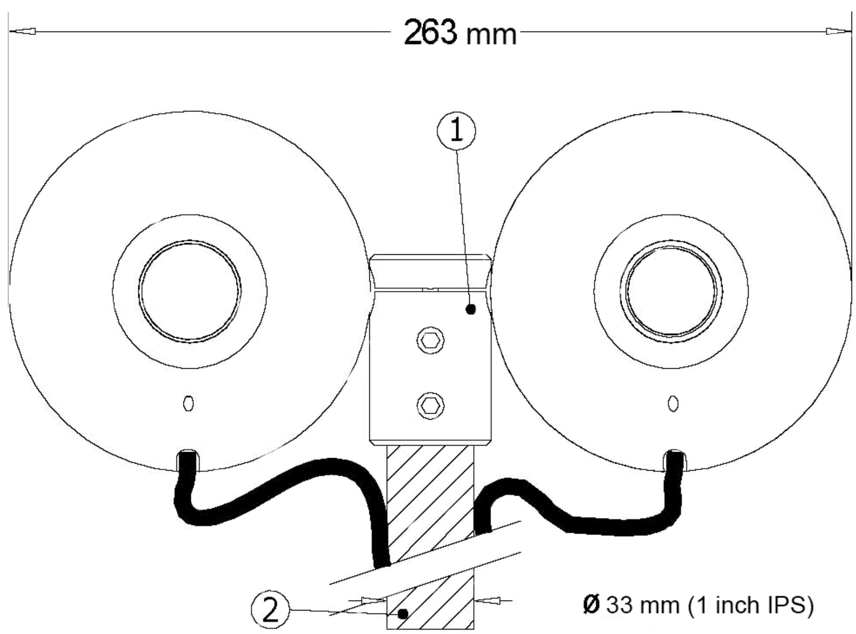


*FIGURE 5-1. Dimensions of the NR01 in mm:*
*(1) 2-Axis Leveling Assembly, (2) Mounting Arm*

**Features:**

- Internal RTD provides temperature compensation of measurements
- Research-grade performance
- Internal 1-W heater reduces formation of dew and melts frost
- Separate outputs of short wave and long wave infrared radiation for better accuracy and more thorough quality assurance
- Robust—only requiring limited maintenance
- Compatible with Campbell Scientific CRBasic dataloggers: CR6, CR1000, CR3000, CR5000, and CR9000(X). The CR1000 and CR9000(X) requires the 4WPB100 PRT Bridge Module to measure the internal RTD.

**TABLE 5-1. General Specifications**

| | |
|---|---|
| **Expected accuracy** | ± 10 % for 12 hour totals, day and night |
| **Operating temperature** | –40 to 80 °C |
| **Sensitivity** | All sensors have individual calibration factors |
| **$T_{pyrgeometer}$** | PT100 DIN class A |
| **$T_{pyrgeometer}$ accuracy** | Within ± 1 ºC |
| **$T_{pyrgeometer}$ options** | A user-supplied temperature sensor can be inserted into the pyrgeometer connection body. Add gland M12 x 1.5 |
| **Heater** | 90 Ohms, 1.6 W at 12 Vdc; 16 Vdc Max |
| **2 axis leveling assembly** | Included, hexagon drive set screw size 2.0 mm, pipe size 1 inch IPS |
| **Radiation shields** | Four shields included |
| **Cable length** | User specified (in feet). Maximum length is 100 ft. |
| **Cable diameter** | 5.4 mm (2 cables) |
| **Weight** | Instrument only 1.3 kg (2.0 lb)<br>With 5 m cable: 1.3 kg (2.9 lb) |
| **Dimensions** | 26.3 x 11.3 x 12.1 cm ((10.4 x 4.4 x 4.8 in) |
| **Recommended recalibration interval** | Every 2 years |
| **CE compliance** | NR01 is compliant with CE directives. |

| TABLE 5-2. Pyranometer Specifications | |
|---|---|
| **Sensor** | Hukseflux's thermopile pyranometer |
| **Overall classification according to ISO 9060 / WMO** | Second class pyranometer |
| **Response time for 95 % response** | 18 s |
| **Zero offset a (response to 200 $W/m^2$ net thermal radiation)** | < 15 $W/m^2$ |
| **Zero offset b (response to 5 k/h change in ambient temperature)** | < 4 $W/m^2$ |
| **Non-stability** | < 1% change per year |
| **Non-Linearity** | < ± 2.5% |
| **Directional response for beam radiation** | Within ± 25 $W/m^2$ |
| **Spectral selectivity** | ± 5% (305 to 2000 nm) |
| **Temperature response (within an interval of 50 °C)** | Within 6% (–10 to 40 °C) |
| **Tilt response** | Within ± 2% |
| **Sensitivity** | 10 to 40 $\mu V/Wm^{-2}$ |
| **Expected voltage output** | Application with natural solar radiation: –0.1 to 50 mV |
| **Sensor resistance** | Between 40 and 60 Ohms (without trimming) |
| **Power required** | Zero (passive sensor) |
| **Range** | To 2000 $Wm^{-2}$ |
| **Spectral range** | 305 to 2800 nm (50% transmission points) |
| **Required programming** | $\Phi = U / E$ |
| **Expected accuracy for daily sums** | ± 10% |
| **Calibration traceability** | To WRR, procedure according to ISO 9847 |

| TABLE 5-3. Pyrgeometer Specifications | |
|---|---|
| **Sensor** | IR01 pyrgeometer |
| **Overall classification according to ISO / WMO** | Not applicable |
| **Response time for 95 % response** | 18 s |
| **Window heating offset (response to 1000 W/m$^2$ net thermal radiation)** | < 15 W/m$^2$ |
| **Zero offset b (response to 5 k/h change in ambient temperature)** | < 4 W/m$^2$ |
| **Non-Stability** | < 1% change per year |
| **Non-Linearity** | < ± 2.5% |
| **Field of view** | 150 degrees |
| **Spectral selectivity** | Not specified |
| **Temperature response (within an interval of 50 °C)** | Within 6% (–10 to 40 °C) |
| **Tilt response** | Within ± 2% |
| **Sensitivity** | 5 – 15 µV/Wm$^{-2}$ |
| **Expected voltage output** | Meteorological application: –5 to 5 mV |
| **Sensor resistance** | Between 100 and 400 Ohms |
| **Power required** | Zero (passive sensor) |
| **Range** | To 1000 Wm$^{-2}$ |
| **Spectral range** | 4500 to 50000 nm (50% transmission points) |
| **Required programming** | $\Phi = U / E$ (in case of net radiation only)<br>$\Phi = (U / E) + 5.67.10^{-8}\,T^4$ (absolute radiation), with T from PT100 measurement |
| **Expected accuracy for daily sums** | ± 10% |
| **Calibration traceability** | International temperature standard |

# 6. Installation

## 6.1 NR01 Construction

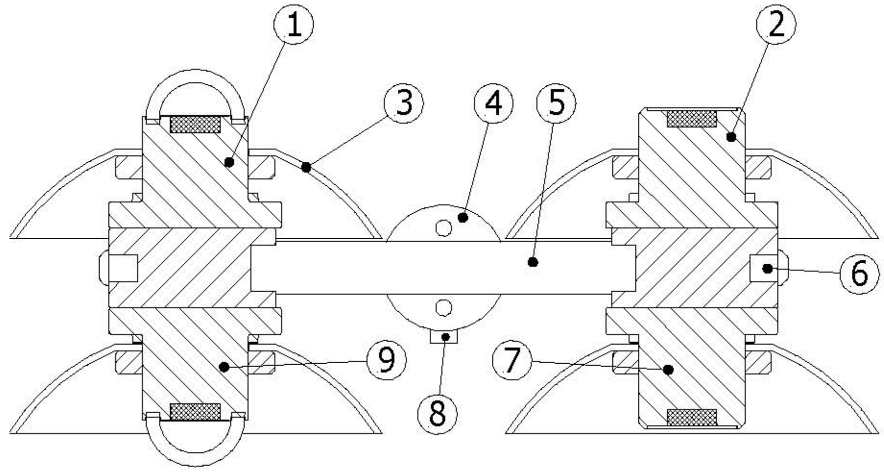


*FIGURE 6-1. The NR01 Four-Component Net Radiation Sensor*

*(1) $SW_{in}$ solar radiation sensor or pyranometer,*
*(2) $LW_{in}$ Far Infrared radiation sensor or pyrgeometer*
*(3) radiation shield*
*(4) leveling assembly for x- and y axis, block plus bolts for x-axis adjustment*
*(5) leveling assembly for x- and y axis, horizontal rod*
*(6) connection body containing the PT100 temperature sensor, heater, and hole for user-supplied temperature sensor (add cable gland M8)*
*(7) $LW_{out}$ Far Infrared radiation sensor or pyrgeometer*
*(8) leveling assembly for x- and y-axis, bolts for y-axis adjustment*
*(9) $SW_{out}$ solar radiation sensor or pyranometer*

*A level is located under the radiation screens.*

## 6.2 Mounting

The NR01 has a hole suitable for a 1-inch IPS pipe (33 mm diameter) for mounting the NR01 onto a CM204 or CM206 crossarm. The crossarm can be mounted to any pole with a 25-mm to 54-mm outer diameter. However, for most applications, Campbell Scientific recommends attaching the crossarm to a CM310-series pole so that the sensor is above vegetation. You can also mount the crossarm to the tripod or tower that supports the datalogger's enclosure.

Slightly loosen the two bolts at the opposite end of the tube mount (4 in FIGURE 6-1) and rotate the sensor mount tube to level the sensor in the two axes. Once the sensor is leveled, tighten all of the Allen bolts, restricting further movement of the sensor.

TABLE 6-1 gives other general guidelines for the positioning and installation of the sensor.

| TABLE 6-1. Recommendations for Installation of the NR01 | |
|---|---|
| Location | Location of measurement should be representative of the total surrounding area, in particular in case the NR01 is used for environmental net radiation measurements. If possible, mount the sensor on a separate pole at least 25 ft away from main logger tower or tripod. |
| Mechanical mounting | A 2-axis leveling assembly is included as part of the sensor mount which is suitable for a range of pipe diameters, max 1-inch IPS pipe (33 mm diameter). |
| Radiation detection | Avoid objects that cast shadows or reflections on the instrument. This includes both incoming and outgoing radiation. |
| Leveling | Use the bubble-level to see if the instrument is mounted horizontally. For viewing the level, the radiation screens must be removed. Alternatively, a spirit level can carefully be put on the pyrgeometer window. |
| Orientation | By convention, with the wiring to the nearest pole (north in the northern hemisphere, south in the southern hemisphere). |
| Height of installation | In case of inverted installation, a height of approximately 4 ft (1.5 m) above ground is recommended by the WMO (to get good spatial averaging). |
| Tilt | The NR01 should typically be installed horizontally, but for some applications, may be installed in a tilted position. In all cases, it will measure the fluxes that are incident on the surface that is parallel to the sensor surface. |

## 6.3 Datalogger Wiring

The four radiation outputs can be measured using differential or single-ended inputs on the datalogger. A differential voltage measurement is recommended because it has better noise rejection than a single-ended measurement. When differential inputs are used, jumper the low side of the input to ⏚ to keep the signal within the common mode range.

Cables generally act as a source of signal distortion by picking up capacitively coupled noise. Therefore, Campbell Scientific recommends keeping the distance between the datalogger and sensor as short as possible.

**WARNING** **The sensor has two cables with similar color schemes. It is important to make sure you identify cable 1 and cable 2 correctly, especially before connecting any source of power such as to the heater. Failure to do so may damage the sensor.**

### 6.3.1 Using a 4WPB100

The CR1000 and CR9000(X) require the 4WPB100 module (FIGURE 6-2) to interface the PT100 to the datalogger. Cable 1 is used to connect the pyranometer and pyrgeometer (TABLE 6-2 and TABLE 6-3). Cable 2 connects the PT100 to the 4WPB100 and datalogger (TABLE 6-4).

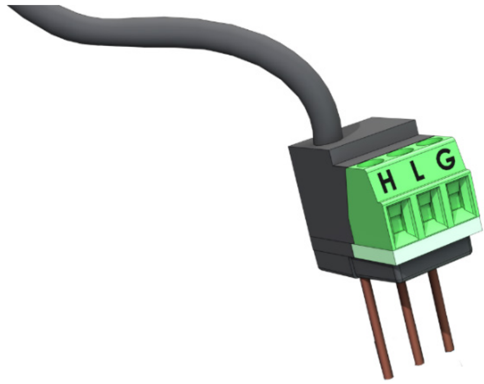


*FIGURE 6-2. 4WPB100 Module*

**NOTE** If free channels are limited, it is possible to measure the PT100 sensor using a 3WHB10K terminal input module, with only a slight loss of accuracy. This only requires one differential channel. Please refer to the documentation for that module for further details.

**TABLE 6-2. Cable 1-to-Datalogger Connections when using Differential Measurements and the 4WPB100***

| Wire Label | Color | CR1000, CR9000(X) |
|---|---|---|
| Pyranometer Up Sig | Red | Differential Input (H) |
| Pyranometer Up Ref | **Blue | Differential Input (L) |
| Pyranometer Down Sig | White | Differential Input (H) |
| Pyranometer Down Ref | **Green | Differential Input (L) |
| Pyrgeometer Up Sig | Brown | Differential Input (H) |
| Pyrgeometer Up Ref | **Yellow | Differential Input (L) |
| Pyrgeometer Down Sig | Purple | Differential Input (H) |
| Pyrgeometer Down Ref | **Grey | Differential Input (L) |
| Shield | Shield | ⏚ |

*Ensure that it is cable 1 before connecting.
**Jumper to ⏚ with user supplied wire.

| TABLE 6-3. Cable 1-to-Datalogger Connections when using Single-Ended Measurements and the 4WPB100* | | |
|---|---|---|
| **Wire Label** | **Color** | **CR1000, CR9000(X)** |
| Pyranometer Up Sig | Red | Single-Ended Input |
| Pyranometer Up Ref | Blue | ⏚ |
| Pyranometer Down Sig | White | Single-Ended Input |
| Pyranometer Down Ref | Green | ⏚ |
| Pyrgeometer Up Sig | Brown | Single-Ended Input |
| Pyrgeometer Up Ref | Yellow | ⏚ |
| Pyrgeometer Down Sig | Purple | Single-Ended Input |
| Pyrgeometer Down Ref | Grey | ⏚ |
| Shield | Shield | ⏚ |
| *Ensure that it is cable 1 before connecting. | | |

| TABLE 6-4. Cable 2 Connections to 4WPB100 and Datalogger* | | | |
|---|---|---|---|
| **Wire Label** | **Color (Cable 2)** | **4WPB100** | **CR1000, CR9000(X)** |
| | | Black Wire | Voltage Excitation (VX) |
| | | H | Differential Input (H) |
| Current Excite | Red | L | Differential Input (L) |
| Current Return | Blue | G | ⏚ |
| PT100 Signal | White | | Differential Input (H) |
| PT100 Signal Ref | Green | | Differential Input (L) |
| *Ensure that it is cable 2 before connecting. | | | |

### 6.3.2 Using the Datalogger's Current Excitation Output

The PT100 sensor can connect directly to the CR6, CR3000, and CR5000 dataloggers because they have current excitation outputs (TABLE 6-5).

**TABLE 6-5. CR6, CR3000, and CR5000 Connections for Differential Measurement and using the Current Excitation to Measure the PT100 Sensor**

| Wire Label | Color | CR6* | CR3000, CR5000 |
|---|---|---|---|
| **Cable 1 (ensure it is cable 1 before connecting)** | | | |
| Pyranometer Up Sig | Red | U configured as a differential input | Differential Input (H) |
| Pyranometer Up Ref | **Blue | U configured as a differential input | Differential Input (L) |
| Pyranometer Down Sig | White | U configured as a differential input | Differential Input (H) |
| Pyranometer Down Ref | **Green | U configured as a differential input | Differential Input (L) |
| Pyrgeometer Up Sig | Brown | U configured as a differential input | Differential Input (H) |
| Pyrgeometer Up Ref | **Yellow | U configured as a differential input | Differential Input (L) |
| Pyrgeometer Down Sig | Purple | U configured as a differential input | Differential Input (H) |
| Pyrgeometer Down Ref | **Grey | U configured as a differential input | Differential Input (L) |
| **Cable 2 (ensure it is cable 2 before connecting)** | | | |
| PT100 Signal | White | U configured as a differential input | Differential Input (H) |
| PT100 Signal Ref | Green | U configured as a differential input | Differential Input (L) |
| Current Excite | Red | U configured as a current excitation | Current Excitation IX |
| Current Return - | Blue | U configured as a current excitation | Current Excitation IXR |
| Shield (both cables) | Clear | ⏚ | ⏚ |

*U channels are automatically configured by the measurement instruction.
**Jumper to AG or ⏚ with user-supplied wire.

## 6.4 Connecting and Using the Heater

Only use the sensor heater when there is risk of dew forming on the sensors, especially for low power installations. Furthermore, the heater should be turned on and off infrequently as it may take some time for the sensor to come to thermal equilibrium. No damage will result if the heater is powered permanently, but as with all thermopile sensors, it is best if the sensor operates at ambient temperatures and is not subject to rapidly changes of temperature.

The sensor power can be controlled using one of the 12 V power switches built into Campbell dataloggers or using an external solid-state switch such as a PSW12/SW12. The heater current drain is approximately 140 mA from a 12 V battery. Connect the ground return from the heater, either directly to the battery, or to a G terminal close the power input to the logger (i.e., not to an analog ground near the measurement inputs).

The heater power can be controlled by adding instructions to the datalogger program, that turns on the heater only when the light level falls below

20 W m$^{-2}$ or, if a measurement of air humidity is available, when the dewpoint of the air falls to within 1 °C of the sensor body temperature. Appendix A.3, *CR3000 Program that Controls Heater* *(p. A-6)*, provides an example CR3000/CR5000 program that controls the NR01 heater.

## 6.5 Installation of the Radiation Shields

Radiation shields can be installed and removed using a hex-head wrench (bolt size 2.0 mm). See the drawing below. Radiation shields are beneficial for instrument measurement accuracy and instrument and cable lifetime. They also serve as rain and snow shield. However, the instrument should function within specifications without the radiation shield.

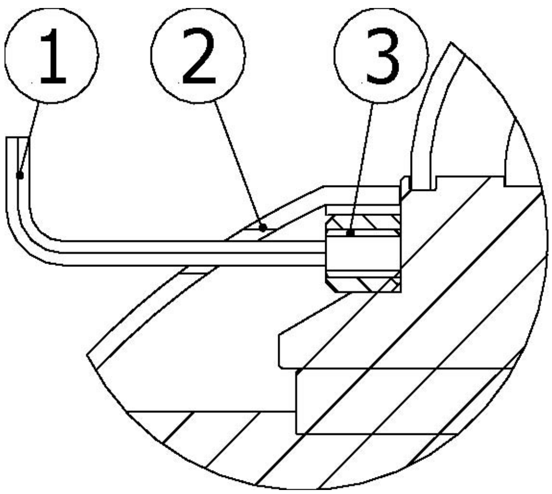


*FIGURE 6-3. Installation and removal of radiation shields: (1) hex-head wrench, (2) radiation screen, (3) hexagon drive set screw*

## 6.6 Datalogger Programming

Programming basics for CRBasic dataloggers are provided in the following sections. Equations used to calculate solar parameters and measurement details are provided in Section 7, *Operation* *(p. 13)*. Complete program examples for a CRBasic datalogger can be found in Appendix A, *Example Programs* *(p. A-1)*. Programming basics and programming examples for Edlog dataloggers are provided at *www.campbellsci.com/old-manuals*.

### 6.6.1 Pyranometer/Pyrgeometer Measurements

The NR01 outputs four voltages that typically range from 0 to 50 mV for the SR01 pyranometers, and ±5 mV for the IR01 pyrgeometer. These voltages are measured using either differential voltage measurements (**VoltDiff** in CRBasic) or single-ended measurements (**VoltSE** in CRBasic). Differential voltage measurements are recommended because they provide better noise rejection than single-ended measurements.

If differential channels are not available, single-ended measurements can be used. The acceptability of single-ended measurements can be determined by comparing the results of single-ended and differential measurements made under the same conditions.

### 6.6.2 Calibration Factors

Each NR01 is provided with a *Certificate of Calibration* by the manufacturer. This certificate shows the sensor serial number and sensitivity for each of the four component sensors. The individual calibration factors are unique to the individual sensor and must be applied in the datalogger program to convert the voltages to energy fluxes in W $m^{-2}$.

The calibration factor is in units of µV/(W $m^{-2}$), which needs to be converted to units of (W $m^{-2}$)/mV for the multiplier parameter in the datalogger program. To convert the units, divide the calibration factor into 1000. For example, if the calibration factor is 7.30 µV/(W $m^{-2}$), the multiplier is 1000/7.3 = 136.99 (W $m^{-2}$)/mV.

## 6.7 Instrument-Inversion Test

Campbell Scientific recommends performing the instrument-inversion test after installation. This test consists of inverting the instrument position (180 degrees turn) and looking at the output signals. The instrument output should have the same magnitude but a reversed sign (so + to – and – to +). For best results, perform this test on a clear day—preferably around noon (with the sun high in the sky).

Deviations within ±10% can be tolerated. For optimal testing of pyrgeometers, the test should be repeated on a clear night.

# 7. Operation

## 7.1 Measurement Principle

The NR01 typically measures net-radiation. The four components of net radiation are measured and the net radiation is calculated:

**NOTE** The temperature ($T_{pyrgeo}$) for the following formula is in Kelvin. If the temperature is measured in degrees Celsius, add 273.15 to the $T_{pyrgeo}$ value.

$$SW_{in} = U_{pyrano,\ up} / E_{pyrano,\ up} \qquad 7\text{-}1$$

$$SW_{out} = U_{pyrano,\ down} / E_{pyrano,\ down} \qquad 7\text{-}2$$

$$LW_{in} = (U_{pyrgeo,\ up} / E_{pyrgeo,\ up}) + 5.67.10^{-8}\ (T_{pyrgeo})^4 \qquad 7\text{-}3$$

$$LW_{out} = (U_{pyrgeo,\ down} / E_{pyrgeo,\ down}) + 5.67.10^{-8}\ (T_{pyrgeo})^4 \qquad 7\text{-}4$$

The instrument temperature is cancelled in the $LW_{net}$:

$$LW_{net} = U_{pyrgeo,\ up} / E_{pyrgeo,\ up} - U_{pyrgeo,\ down} / E_{pyrgeo,\ down} \qquad 7\text{-}5$$

$$SW_{net} = U_{pyrano,\ up} / E_{pyrano,\ up} - U_{pyrano,\ down} / E_{pyrano,\ down} \qquad 7\text{-}6$$

$$NR = SW_{net} + LW_{net} \qquad 7\text{-}7$$

The equation for the $SW_{albedo}$ is as follows:

$$SW_{albedo} = SW_{in} / SW_{out} \quad 7\text{-}8$$

**NOTE** The following equations assume the temperature is in Kelvin. Add 273.15 to equations 7-9 and 7-10 for temperature in degree Celsius.

$$T_{surface} = (LW_{out} / 5.67.10^{-8})^{1/4} \quad 7\text{-}9$$

$$T_{sky} = (LW_{in} / 5.67.10^{-8})^{1/4} \quad 7\text{-}10$$

### 7.1.1 Pyranometers

A pyranometer measures the solar or SW radiation flux from a field of view of 180 degrees. The atmospheric SW radiation spectrum extends roughly from 300 to 2800 nm. The pyranometer should cover that spectrum with a spectral sensitivity that is as flat as possible.

For a flux measurement, it is required by definition that the response to beam radiation varies with the cosine of the angle of incidence. For example, full response occurs when the solar radiation hits the sensor perpendicularly (normal to the surface, sun at zenith, 0 degrees angle of incidence); zero response occurs when the sun is at the horizon (90 degrees angle of incidence, 90 degrees zenith angle), and half a response occurs at 60 degrees angle of incidence. It follows from the definition that a pyranometer should have a so-called directional response or cosine response that is close to the ideal cosine characteristic.

In order to attain the proper directional and spectral characteristics, a pyranometer's main components are:

1. Thermopile sensor with a black coating – absorbs all solar radiation, provides a flat spectrum covering the 300 to 50000-nanometer range, and has a near-perfect cosine response.

2. Glass dome – limits the spectral response from 300 to 2800 nanometers (cutting off the part above 2800 nm) while preserving the 180 degrees field of view (FIGURE 7-1). Another function of the dome is that it shields the thermopile sensor from convection.

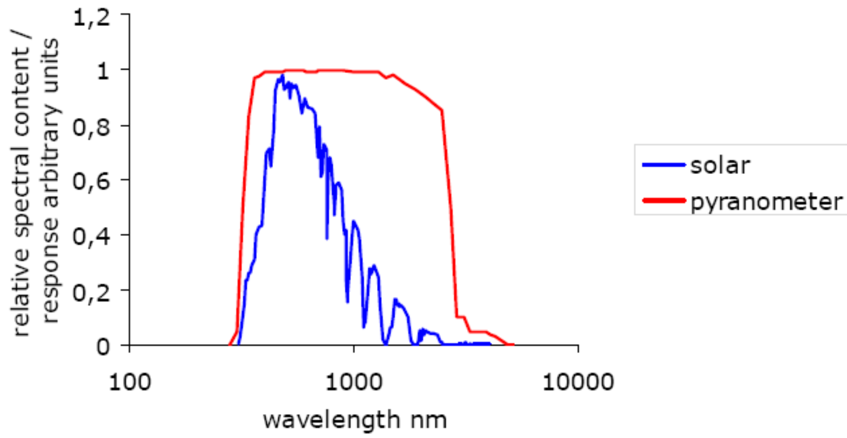


*FIGURE 7-1. Spectral response of the pyranometer compared to the solar spectrum. The pyranometer only cuts off a negligible part of the total solar spectrum.*

The black coating on the thermopile sensor absorbs the solar radiation. This radiation is converted to heat. The heat flows through the sensor to the pyranometer housing. The thermopile sensor generates a voltage output signal that is proportional to the solar radiation.

$$SW_{in} = U_{pyrano,\,up} / E_{pyrano,\,up} \qquad 7\text{-}11$$

In case of the NR01, the pyranometer is type SR01. This is a second-class pyranometer according to the WMO and ISO classification system (ISO 9060).

The atmospheric solar radiation consists of two components—direct radiation (in a beam from the sun) and diffuse radiation from the sky.

For down facing instruments, the earth surface reflects part of the solar radiation, depending on the local surface properties. If there is direct radiation, this often is the dominant source of energy. Because the solar position is changing, this implies that for a pyranometer the directional response is quite important.

TABLE 7-1 summarizes the main sources of measurement errors for the SR01. The error in the directional response is caused by non-perfect optical properties of the dome and coating. The infrared offset is produced when the low temperature sky cools off the instrument dome. Because the LW radiation balance between dome and sky is negative, a negative sensor offset occurs as the dome cools.

**TABLE 7-1. Main Measurement Errors in the SW Signal**

| Source | Maximum Error |
|---|---|
| Directional response | ±30 W/m$^2$ on $SW_{in}$ in practice this level is ±15 W/m$^2$ on $SW_{in}$ at 1000 W/m$^2$ $SW_{in}$ |
| Infrared offset | –15 W/m$^2$ on $SW_{in}$ at –200 W/m$^2$ $LW_{net}$ |
| Temperature dependence | ±5% for the entire range |

### 7.1.2 Pyrgeometers

A pyrgeometer should measure the far infrared or LW radiation flux from a field of view of 180 degrees. The atmospheric LW radiation spectrum extends roughly from 4500 to 50000 nm. The pyrgeometer should cover that spectrum with a spectral sensitivity that is as flat as possible.

For a flux measurement, by definition, the response to beam radiation varies with the cosine of the angle of incidence. For example, full response occurs when the radiation hits the sensor perpendicularly (normal to the surface, source at zenith, 0 degrees angle of incidence); zero response occurs when the radiation comes from the horizon (90 degrees angle of incidence, 90 degrees zenith angle), and half a response occurs at 60 degrees angle of incidence. It follows from the definition that a pyrgeometer should have a so-called directional response or cosine response that is close to the ideal cosine characteristic.

To attain the proper directional and spectral characteristics, a pyrgeometer's main components are:

1 Thermopile sensor with a black coating – absorbs all LW and SW radiation, provides a flat spectrum covering the 300 to 50000 nanometer range, and has a near-perfect cosine response.

2 Silicon window with solar blocking – limits the spectral response from 4500 to 50000 nanometers (cutting off the part below 4500 nm) while preserving the 150 degrees field of view (not the ideal 180 degrees). Another function of the window is that it shields the thermopile sensor from convection (FIGURE 7-2).

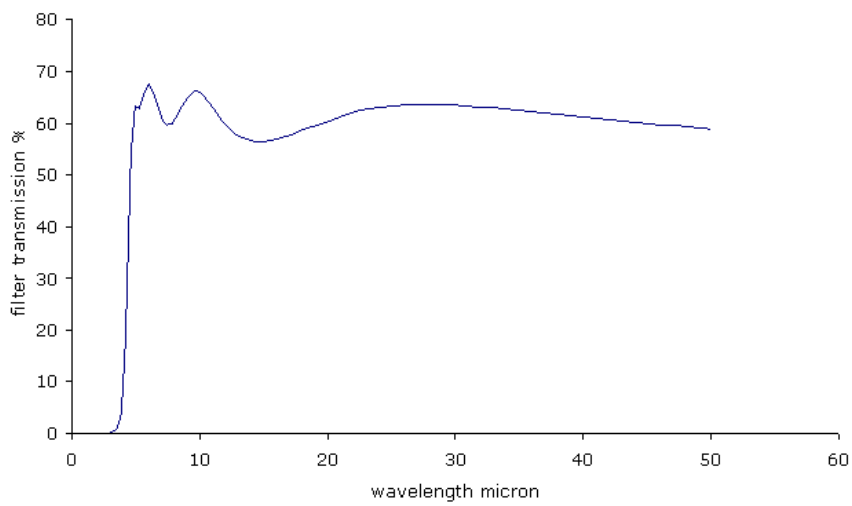


*FIGURE 7-2. Spectral response of the pyrgeometer compared to the atmospheric LW spectrum*

The black coating on the thermopile sensor absorbs the LW radiation. This radiation is converted to heat. The heat flows through the sensor to the housing. The thermopile sensor generates a voltage output signal that is proportional to the LW radiation that is exchanged between sensor and source. However, the sensor itself also irradiates LW radiation. This is according to Plank's law, so that the pyrgeometer thermopile signal is composed of the incoming radiation minus the outgoing radiation. In order to estimate the outgoing component, the pyrgeometer temperature is measured independently, using a PT100 or a user-supplied temperature sensor. Equation 7-12 calculates the incoming LW radiation assuming $T_{pyrgeo}$ is in Kelvin:

$$LW_{in} = (U_{pyrgeo,\ up} / E_{pyrgeo,\ up}) + 5.67.10^{-8}\ (T_{pyrgeo})^4 \qquad 7\text{-}12$$

For $LW_{out}$ a similar formula is valid. The equations are the same for up and down facing instruments.

It is possible to calculate temperatures of the objects within the field of view of the instrument, assuming these are uniform- temperature blackbodies (emission coefficient of 1). For example, equation 7-13 calculates, in Kelvin, the sky temperature:

$$T_{sky} = (LW_{in} / 5.67.10^{-8})^{1/4} \qquad 7\text{-}13$$

The NR01's pyrgeometers are type IR01. Pyrgeometers are not classified by the ISO or WMO.

The atmospheric $LW_{in}$ radiation essentially consists of two components:

1 Low temperature radiation from the universe, filtered by the atmosphere. The atmosphere is transparent for this radiation in the so-called atmospheric window (around 10 to 15 micrometer wavelength).

2 Higher temperature radiation emitted by atmospheric gasses.

Down facing instruments are presumably looking directly at the surface, which behaves like a normal blackbody.

As a first approximation, the sky can, be seen as a cold temperature source with its lowest temperatures at zenith and getting warmer at the horizon. The uniformity of this LW source is much better than that in the solar (SW) range, where the sun is a dominant and non-uniform contributor. This explains why a pyrgeometer with 150 degrees field of view can perform a good measurement.

TABLE 7-2 summarizes the main measurement errors for the IR01. The error in the directional response is caused by non-perfect field of view. The window-heating offset occurs when solar radiation heats up the instrument window, producing a positive sensor offset.

**TABLE 7-2. Main Measurement Errors in the LW Signal**

| Source | Maximum Error |
|---|---|
| Directional response | 8 $W/m^2$ on $LW_{in}$ at -100 $W/m^2$ $LW_{net}$ |
| Window heating offset | +15 $W/m^2$ on $LW_{in}$ at 1000 $W/m^2$ $SW_{in}$ |
| Temperature dependence | ±5% for the entire range |

### 7.1.3 Expected Measurement Results

The average energy balance at the earth surface strongly depends on the:

- Latitude (mostly for SW)
- Local surface properties (SW and LW)
- Local surface temperature (LW)

TABLE 7-3 summarizes the average global values. The average net radiation at the earth surface is positive, and the remaining energy is used for convective heat transport and evaporation.

**TABLE 7-3. Average Global Radiation Values at the Earth Surface**

| Type | $SW_{in}$ | $SW_{out}$ | $SW_{net}$ | $LW_{in}$ | $LW_{out}$ | $LW_{net}$ | Net |
|---|---|---|---|---|---|---|---|
| Units | $W/m^2$ | $W/m^2$ | $W/m^2$ | $W/m^2$ | $W/m^2$ | $W/m^2$ | $W/m^2$ |
| Value | 198 | –30 | 168 | 324* | –390** | –66 | 102 |

*$LW_{in}$ value assumes a sky temperature of 2 °C.
**$LW_{out}$ value assumes a surface temperature of 14 °C.

**NOTE** The LW radiation values in TABLE 7-3 are corrected for sensor temperature. The values in TABLE 7-4 are not corrected for sensor temperature.

On a smaller timescale, the most important factors are:

- solar position
- cloud cover

The ambient air temperature is less important because cloud base temperature tends to follow surface temperature.

TABLE 7-4 provides the expected outputs. This table makes a distinction between the day and night (D/N), cloudy and clear (CD / CR) conditions, and high and low ambient air temperatures.

The raw reading of the upward facing pyrgeometer is generally close to zero when the sensor temperature is near the ground temperature. Expect small negative readings when the sensor is above cooled surfaces such as water or transpiring vegetation, or small positive readings when the surface is emitting heat (e.g., warm soil at night). The instrument temperature is normally close to air temperature.

**TABLE 7-4. Expected NR01 Outputs**

| D / N | CD / CR | Ambient air temp. | pyrgeo down# | pyrgeo up# | pyrano down | pyrano up | $T_{sky}$ | $T_{ground}$ |
|---|---|---|---|---|---|---|---|---|
| | | °C | W/m² | W/m² | W/m² | W/m² | °C | °C |
| | | | | | | | | |
| D | CD | +20 | 0 | 0 | 0 to 500 | 0 to 150 | 20 | +20 |
| D | CD | –20 | 0 | 0 | 0 to 500 | 0 to 150 | –20 | –20 |
| D | CR | +20 | –70** | 0 | 0 to 1500 | 0 to 400 | +1 | +20 |
| D | CR | –20 | –70** | 0 | 0 to 1500 | 0 to 400 | –50 | –20 |
| N | CD | +20 | 0 | 0 | 0 | 0 | +20 | +20 |
| N | CD | –20 | 0 | 0 | 0 | 0 | –20 | –20 |
| N | CR | +20 | –70* | 0 | 0*** | 0 | 1 | +20 |
| N | CR | –20 | –70* | 0 | 0*** | 0 | 50 | –20 |

#Outputs listed for both of the pyrgeometers are not compensated for sensor temperature. For example, to correct for sensor temperature when the sensor temperature is 14 °C, you should add 385 W/m² to the pyrgeometer signals.

*At night, dew deposition may affect the downward facing pyrgeometer's output. In that case, the signal may drop to 0 W/m², producing a maximum error of +100 W/m². Campbell Scientific recommends activating the heater to avoid dew deposition.

**During the day, the window-heating offset may affect the downward facing pyrgeometer's output. This can produce a maximum error of +15 W/m².

***At night, the infrared offset may affect the downward facing pyranometer's output. The maximum error of this offset is -25 W/m².

# 8. Maintenance and Troubleshooting

## 8.1 Maintenance

The NR01 requires little maintenance. Dirt should be cleaned off the domes every few weeks. Usually errors in functionality appear as unreasonably large or small measured values. See TABLE 8-1 for specific maintenance recommendations.

**TABLE 8-1. Maintenance Recommendations**

| |
|---|
| Critical review of data |
| Cleaning of dome using water or alcohol every few weeks |
| Inspection of dome interior; no condensation every few weeks |
| Inspection of cables for open connections every few weeks |
| Perform the procedure provided in Section 6.7, *Instrument-Inversion Test (p. 13)*. |
| Recalibration: suggested every 2 years, typically by intercomparison with a higher standard in the field. |

## 8.2 Troubleshooting

### 8.2.1 Data Quality Assurance

To assure quality data, look for unrealistic values when analyzing:

- Trends in $SW_{in}$ absolute signal
- SW albedo
- Correlation of $SW_{in}$ and $LW_{in}$
- SW night time signals
- Correlation of relation $LW_{out}$ and surface temperature

### 8.2.2 Problem Diagnosis

TABLE 8-2 contains information used to diagnosis problems whenever the sensor does not function properly.

**TABLE 8-2. Troubleshooting for the NR01**

| | |
|---|---|
| The sensor does not give any signal | Typically, an error is due to either a short circuit or an open connection. Both can be detected by impedance / resistance measurements at the cable end.<br>In case of open circuits: open the instrument and check the internal connections (see TABLE B-3). |
| The sensor signal is unrealistically high or low | Check if the right calibration factors are entered into the algorithm. Please note that each sensor has its own individual calibration factor.<br>Check if the voltage reading is divided by the calibration factor by review of the algorithm.<br>Check the condition of the leads at the datalogger.<br>Check the cabling condition looking for cable breaks.<br>Check the data acquisition by applying an mV source to it in the 1 mV range.<br>Perform a sensor-inversion test (see Section 6.7, *Instrument-Inversion Test (p. 13)*).<br>Open the instrument and check the internal connections (see TABLE B-3). |
| The sensor signal shows unexpected variations | Check the presence of strong sources of electromagnetic radiation (radar, radio etc.).<br>Check the condition of the shielding.<br>Check the condition of the sensor cable.<br>Open the instrument and check the internal connections (see TABLE B-3). |

# Appendix A. Example Programs

## A.1 CR1000 Program Using Differential Channels

This program requires six differential channels and the 4WPB100 module to measure the four radiation outputs and the PT100 temperature sensor, connected on differential channels 1 through 6. The program measures the sensors every two seconds, then calculates and stores the following data to final storage every 60 minutes:

Year
Julian Day
Hour/Minute
Avg SR01 Up (short wave radiation)
Avg SR01 Down (short wave radiation)
Avg IR01 Up (long wave radiation)
Avg IR01 Down (long wave radiation)
Avg NR01 temperature (degrees C)
Avg NR01 temperature (degrees K)
Avg Net shortwave radiation
Avg Net long wave radiation
Avg Albedo
Avg Total Net radiation
Avg temperature corrected IR01 Up
Avg temperature corrected IR01 Down

**Wiring for Program Example 1**

| Color | Function | Example CR1000 Program Channels Used |
|---|---|---|
| Red | SR01 Up Signal | 1H |
| *Blue | SR01 Up Reference | 1L |
| White | SR01 Down Signal | 2H |
| *Green | SR01 Down Reference | 2L |
| Brown | IR01 Up Signal | 3H |
| *Yellow | IR01 Up Reference | 3L |
| Purple | IR01 Down Signal | 4H |
| *Grey | IR01 Down Reference | 4L |
| Shield | Shield | ⏚ |
| *Jumper to ⏚ with user supplied wire. | | |

**PT100 Temperature Sensor Connections to 4WPB100 and Datalogger**

| Color | Function | 4WPB100 | CR1000 |
|---|---|---|---|
| Black | | Wire | EX1 |
| | | H | 5H |
| Red | PT100 Excitation + | L | 5L |
| Blue | PT100 Excitation – | G | ⏚ |
| White | PT100 Signal + | | 6H |
| Green | PT100 Signal – | | 6L |

**CRBasic Example A-1.  CR1000 Program Measuring NR01**

```
'CR1000

'Declare Variables and Units
Public Batt_Volt
Public SR01Up
Public SR01Dn
Public IR01Up
Public IR01Dn
Public NR01TC
Public NR01TK
Public NetRs
Public NetRl
Public Albedo
Public UpTot
Public DnTot
Public NetTot
Public IR01UpCo
Public IR01DnCo

Units Batt_Volt=Volts
Units SR01Up=W/m2
Units SR01Dn=W/m2
Units IR01Up=W/m2
Units IR01Dn=W/m2
Units NR01TC=Deg C
Units NR01TK=K
Units NetRs=W/m2
Units NetRl=W/m2
Units Albedo=W/m2
Units UpTot=W/m2
Units DnTot=W/m2
Units NetTot=W/m2
Units IR01UpCo=W/m2
Units IR01DnCo=W/m2

'Typical data on the calibration sheet might be
'Sensitivity µV/W/m^2
'Pyranometer UP  SR01    15.35
'Pyranometer DOWN SR01   13.30
'Pyrgeometer UP   IR01   8.5
'Pyrgeometer DOWN IR01   8.2

'So load the four calibration coefficients specific to this sensor (1000/Sensitivity)
Const SR01Upcal = 65.146
Const SR01Downcal = 75.18
Const IR01Upcal = 117.65
Const IR01Downcal = 121.95
```

```
'Define Data Tables
DataTable(Table1,True,-1)
  DataInterval(0,60,Min,10)
  Average(1,SR01Up,FP2,False)
  Average(1,SR01Dn,FP2,False)
  Average(1,IR01Up,FP2,False)
  Average(1,IR01Dn,FP2,False)
  Average(1,NR01TC,FP2,False)
  Average(1,NR01TK,FP2,False)
  Average(1,NetRs,FP2,False)
  Average(1,NetRl,FP2,False)
  Average(1,Albedo,FP2,False)
  Average(1,UpTot,FP2,False)
  Average(1,DnTot,FP2,False)
  Average(1,NetTot,FP2,False)
  Average(1,IR01UpCo,FP2,False)
  Average(1,IR01DnCo,FP2,False)
EndTable

'Main Program
BeginProg
  Scan(2,Sec,1,0)
    'Default Datalogger Battery Voltage measurement Batt_Volt:
    Battery(Batt_Volt)
    'NR01 Net Radiometer measurements SR01Up, SR01Dn, IR01Up, IR01Dn, NR01TC, NR01TK,
    'NetRs, NetRl, Albedo, UpTot, DnTot, NetTot, IR01UpCo, and IR01DnCo
    'For the CR1000, use autorange for the SR01 measurements due to the wide dynamic range
    *  VoltDiff(SR01Up,1,autorange,1,True,0,_50Hz,SR01UpCal,0)
    *  VoltDiff(SR01Dn,1,autorange,2,True,0,_50Hz,SR01DownCal,0)
    *  VoltDiff(IR01Up,1,mV7_5,3,True,0,_50Hz,IR01Upcal,0)
    *  VoltDiff(IR01Dn,1,mV7_5,4,True,0,_50Hz,IR01DownCal,0)
    ** BrHalf4W (NR01TC,1,mV25,mV25,5,Vx1,1,2100,True ,True ,0,250,1.0,0)
    PRT(NR01TC,1,NR01TC,1,0)
    NR01TK=NR01TC+273.15
    NetRs=SR01Up-SR01Dn
    NetRl=IR01Up-IR01Dn
    Albedo=SR01Dn/SR01Up
    UpTot=SR01Up+IR01Up
    DnTot=SR01Dn+IR01Dn
    NetTot=UpTot-DnTot
    IR01UpCo=IR01Up+5.67*10^-8*NR01TK^4
    IR01DnCo=IR01Dn+5.67*10^-8*NR01TK^4
    'Call Data Tables and Store Data
    CallTable(Table1)
  NextScan
EndProg
```

Note: Proper entries will vary with program and input channel usage. For other dataloggers use:
*mV50 range for the CR3000/5000
**mV50 range (both) with 4200 mV excitation for CR3000/5000

# A.2 CR3000 Program Using Differential Channels (no 4WPB100)

Program Example 2 requires five differential channels and one current excitation channel to measure the four radiation outputs and the PT100 temperature sensor. Connection details are given in the header of the program below. The program measures the sensors every second and calculates and stores the following data to final storage every 60 minutes:

Year
Julian Day
Hour/Minute
Avg SR01 Up (shortwave radiation)
Avg SR01 Down (shortwave radiation)
Avg IR01 Up (longwave radiation)
Avg IR01 Down (longwave radiation)
Avg NR01 temperature (degrees C)
Avg NR01 temperature (degrees K)
Avg Net shortwave radiation
Avg Net longwave radiation
Avg Albedo
Avg Total Net radiation
Avg temperature corrected IR01 Up
Avg temperature corrected IR01 Down

**CRBasic Example A-2. CR3000 Program Measuring NR01**

```
'CR3000 Datalogger

'ANALOG INPUT
'1H    SR01 UP - downwelling shortwave radiation signal (red)
'1L    SR01 UP - downwelling shortwave radiation signal reference (blue)
'gnd   NR01 shield (clear)

'2H    SR01 DOWN - upwelling shortwave radiation signal (white)
'2L    SR01 DOWN - upwelling shortwave radiation signal reference (green)

'3H    IR01 UP - downwelling longwave radiation signal (brown)
'3L    IR01 UP - downwelling longwave radiation signal reference (yellow)

'4H    IR01 DOWN - upwelling longwave radiation signal (purple)
'4L    IR01 DOWN - upwelling longwave radiation signal reference (grey)

'6H    NR01 Pt100 (white)
'6L    NR01 Pt100 (green)

'Current Excitation
'IX1   NR01 Pt100 (red)
'IXR   NR01 Pt100 (blue)

'Declare Variables and Units
Public Batt_Volt
Public SR01Up
Public SR01Dn
Public IR01Up
Public IR01Dn
Public NR01TC
Public NR01TK
Public NetRs
Public NetRl
Public Albedo
```

```
Public UpTot
Public DnTot
Public NetTot
Public IR01UpCo
Public IR01DnCo

Units Batt_Volt = Volts
Units SR01Up = W/m2
Units SR01Dn = W/m2
Units IR01Up = W/m2
Units IR01Dn = W/m2
Units NR01TC = Deg C
Units NR01TK = K
Units NetRs = W/m2
Units NetRl = W/m2
Units Albedo = W/m2
Units UpTot = W/m2
Units DnTot = W/m2
Units NetTot = W/m2
Units IR01UpCo = W/m2
Units IR01DnCo = W/m2

'Load the four calibration coefficients specific to this sensor (see example 1)
Const SR01Upcal = 65.146
Const SR01Downcal = 75.18
Const IR01Upcal = 117.65
Const IR01Downcal = 121.95

'Define Data Tables
DataTable(Table1,True,-1)
  DataInterval(0,60,Min,10)
  Average(1,SR01Up,FP2,False)
  Average(1,SR01Dn,FP2,False)
  Average(1,IR01Up,FP2,False)
  Average(1,IR01Dn,FP2,False)
  Average(1,NR01TC,FP2,False)
  Average(1,NR01TK,FP2,False)
  Average(1,NetRs,FP2,False)
  Average(1,NetRl,FP2,False)
  Average(1,Albedo,FP2,False)
  Average(1,UpTot,FP2,False)
  Average(1,DnTot,FP2,False)
  Average(1,NetTot,FP2,False)
  Average(1,IR01UpCo,FP2,False)
  Average(1,IR01DnCo,FP2,False)
EndTable

'Main Program
BeginProg
  Scan(1,Sec,1,0)
  'Default Datalogger Battery Voltage measurement Batt_Volt:
    Battery(Batt_Volt)
  'NR01 Net Radiometer measurements SR01Up, SR01Dn, IR01Up, IR01Dn, NR01TC, NR01TK,
  'NetRs, NetRl, Albedo, UpTot, DnTot, NetTot, IR01UpCo, and IR01DnCo
  'Uses fixed ranges as they fall more in line with the range of sensor outputs, so no need
  'to autorange
    VoltDiff(SR01Up,1,mV50,1,True,200,250,SR01Upcal,0)
    VoltDiff(SR01Dn,1,mV50,2,True,200,250,SR01DownCal,0)
    VoltDiff(IR01Up,1,mV20,3,True,200,250,IR01Upcal,0)
    VoltDiff(IR01Dn,1,mV20,4,True,200,250,IR01DownCal,0)
     'Note maximum sensor temperature with this excitation setting is just over +50 C.
    Resistance (NR01TK,1,mV200,6,Ix1,1,1675,True ,True,200,250,1.0,0)

'Formulate the ratio Rs/R0
    NR01TK=NR01TK/100
    PRT(NR01TK,1,NR01TK,1,273.15)

     'Compute Net short-wave radiation, Net long-wave radiation, Albedo and Net Radiation
```

```
    NR01TC=NR01TK-273.15
    NetRs=SR01Up-SR01Dn
    NetRl=IR01Up-IR01Dn
    Albedo=SR01Dn/SR01Up
    UpTot=SR01Up+IR01Up
    DnTot=SR01Dn+IR01Dn
    NetTot=UpTot-DnTot
    IR01UpCo=IR01Up+5.67*10^-8*NR01TK^4
    IR01DnCo=IR01Dn+5.67*10^-8*NR01TK^4
    'Call Data Tables and Store Data
    CallTable(Table1)
    NextScan
EndProg
```

**NOTE** Proper entries for the input channels will vary with program and input channel usage.

# A.3 CR3000 Program that Controls Heater

This program applies power to the NR01 heater using the SW12V relay controller and the pulse width modulation instruction (PWM ()).

Rather than using 0 °C as a set point for the heater, the program below uses the dewpoint value. The datalogger calculates dewpoint using the relative humidity (RH) measurements provided by the HMP45C Temperature/Relative Humidity probe. Enter 0 °C as the set point for the heater when a temperature/RH probe is not used.

The algorithm turns the heater on/off at 4 Hz. The duty cycle of the pulse is changed depending on how close the radiometer body temperature is to the dewpoint temperature. At or below the dewpoint, the duty cycle is 100%. It drops off linearly to 20% until the body temperature is 5 °C above the dewpoint. For body temperatures greater than 5 °C above the dewpoint, the duty cycle continues to drop linearly, but with a different slope, until 0% at 33 °C above the dewpoint. If necessary, the user can change the two duty-cycle slope transitions.

**CRBasic Example A-3.  CR3000 Program Measuring NR01 and Controlling Heater**

```
'CR3000 Series Datalogger

'*** Wiring ***

'ANALOG INPUT
'5H    HMP45C temperature signal (yellow)
'5L    HMP45C signal reference (white)
'gnd   HMP45C shield (clear)

'6H    HMP45C relative humidity signal (blue)
'6L    short jumper wire to 5L

'10H   NR01 Pt100 signal (white)
'10L   NR01 Pt100 signal reference (green)
'gnd   NR 01 Pt100 shield (silver)

'11H   NR01 downwelling shortwave radiation signal (red)
'11L   NR01 downwelling shortwave radiation signal reference (blue)
'gnd   NR01 shield (silver)

'12H   NR01 upwelling shortwave radiation signal (white)
```

```
'12L   NR01 upwelling shortwave radiation signal reference (green)

'13H   NR01 downwelling longwave radiation signal (brown)
'13L   NR01 downwelling longwave radiation signal reference (yellow)

'14H   NR01 upwelling longwave radiation signal (purple or pink)
'14L   NR01 upwelling longwave radiation signal reference (gray)

'CURRENT EXCITATION
'IX1   NR01 Pt100 current excitation (red)
'IXR   NR01 Pt100 current excitation reference (blue)

'CONTROL PORTS
'C4    SW12V control (green)
'G     SW12V control/power reference (black)

'POWER OUT
'12V   HMP45C power (red)
'      SW12V power (red)
'G     HMP45C power reference (black)

'POWER IN
'12V   datalogger (red)
'G     datalogger (black)

'EXTERNAL POWER SUPPLY
'POS   datalogger (red)
'NEG   datalogger (black)

'SW12V Power Control Module
'SW12V NR 01 heater excitation (brown)
'G     NR 01 heater excitation reference (yellow)

PipeLineMode

'*** Constants ***

Const NR01_SHORT_DW_CAL = 1000/13.41  'Unique NR 01 shortwave downwelling multiplier (1000/15.5).
Const NR01_SHORT_UW_CAL = 1000/13.93  'Unique NR 01 shortwave upwelling multiplier (1000/13.5).
Const NR01_LONG_DW_CAL = 1000/8.8     'Unique NR 01 longwave downwelling multiplier (1000/10.5).
Const NR01_LONG_UW_CAL = 1000/9.4     'Unique NR 01 longwave upwelling multiplier (1000/10.3).

Const MAX_DUTY_CYCLE_1 = 1
Const MAX_DUTY_CYCLE_2 = 0.2
Const DELTA_SET_POINT_1 = 5
Const DELTA_SET_POINT_2 = 28
Const SLOPE_1 = (MAX_DUTY_CYCLE_2-MAX_DUTY_CYCLE_1)/DELTA_SET_POINT_1
Const SLOPE_2 = (-MAX_DUTY_CYCLE_2)/DELTA_SET_POINT_2

'*** Variables ***

Public no_heat_flag As Boolean  'Turn off heater control when TRUE.
Public panel_temp               'Datalogger panel temperature.
Public batt_volt                'Datalogger battery voltage.
Public hmp(2)                   'HMP45C temperature and relative humidity.
Alias hmp(1) = t_hmp            'HMP45C temperature.
Alias hmp(2) = rh_hmp           'HMP45C relative humidity.
Public e_hmp                    'HMP45C vapor pressure.
Public nr01(9)                  'NR 01 net radiometer.
Alias nr01(1) = Rn
Alias nr01(2) = albedo
Alias nr01(3) = Rs_downwell
Alias nr01(4) = Rs_upwell
Alias nr01(5) = Rl_downwell
Alias nr01(6) = Rl_upwell
Alias nr01(7) = t_nr01
Alias nr01(8) = Rl_down_meas
Alias nr01(9) = Rl_up_meas
```

```
Units panel_temp = C
Units batt_volt = V
Units t_hmp = C
Units rh_hmp = percent
Units e_hmp = kPa
Units nr01 = W/m^2
Units albedo = unitless
Units t_nr01 = K

'Net radiometer heater control variables.
Public set_point_temperature
Public duty_cycle

'Working Variables
Dim scratch_out(3)
Alias scratch_out(1) = t_hmp_mean
Alias scratch_out(2) = e_hmp_mean
Alias scratch_out(3) = e_sat_hmp_mean
Dim rh_hmp_mean      'Mean HMP45C relative humidity.
Dim t_dew_hmp_mean   'Mean dew point temperature.
Dim e_sat_hmp        'HMP45C saturation vapor pressure.
Units t_hmp_mean = C
Units e_hmp_mean = kPa
Units e_sat_hmp_mean = kPa
Units rh_hmp_mean = percent
Units t_dew_hmp_mean = C

DataTable (stats,TRUE,-1)
  DataInterval (0,5,Min,10)

  Sample (1,t_hmp_mean,IEEE4)
  Sample (1,e_hmp_mean,IEEE4)
  Sample (1,rh_hmp_mean,IEEE4)
  Sample (1,t_dew_hmp_mean,IEEE4)
  Sample (1,duty_cycle,IEEE4)
  Average (9,Rn,IEEE4,FALSE)
EndTable

DataTable (scratch,TRUE,1)
  TableHide
  DataInterval (0,5,Min,10)

  Average (1,t_hmp,IEEE4,FALSE)
  Average (1,e_hmp,IEEE4,FALSE)
  Average (1,e_sat_hmp,IEEE4,FALSE)
EndTable

BeginProg
  Scan (1,Sec,0,0)
    'Control the net radiometer heater.
    PWM (duty_cycle,4,250,mSec)

    'Datalogger panel temperature.
    PanelTemp (panel_temp,250)

    'Measure battery voltage.
    Battery (batt_volt)

    'Measure the HMP45C temperature and relative humidity.
    VoltDiff (t_hmp,1,mV1000C,5,TRUE,200,250,0.1,-40)
    VoltDiff (rh_hmp,1,mV1000C,6,TRUE,200,250,0.1,0)

    'Measure NR 01 Net Radiometer.
    Resistance (t_nr01,1,mV200,10,Ix1,1,1675,TRUE,TRUE,200,250,1,0)
    VoltDiff (Rs_downwell,1,mV20C,11,TRUE,200,250,NR01_SHORT_DW_CAL,0)
    VoltDiff (Rs_upwell,1,mV20C,12,TRUE,200,250,NR01_SHORT_UW_CAL,0)
    VoltDiff (Rl_down_meas,1,mV20C,13,TRUE,200,250,NR01_LONG_DW_CAL,0)
    VoltDiff (Rl_up_meas,1,mV20C,14,TRUE,200,250,NR01_LONG_UW_CAL,0)
```

```
    'Find the HMP45C vapor pressure and saturation vapor pressure (kPa).
    VaporPressure (e_hmp,t_hmp,rh_hmp)
    SatVP (e_sat_hmp,t_hmp)

    'Compute net radiation, albedo, downwelling and upwelling longwave radiation.
    t_nr01 = t_nr01/100
    PRT (t_nr01,1,t_nr01,1,273.15)

    Rn = Rs_downwell-Rs_upwell+Rl_down_meas-Rl_up_meas
    albedo = Rs_upwell/Rs_downwell
    Rl_downwell = Rl_down_meas+(5.67e-8*t_nr01*t_nr01*t_nr01*t_nr01)
    Rl_upwell = Rl_up_meas+(5.67e-8*t_nr01*t_nr01*t_nr01*t_nr01)

    CallTable (scratch)
    If ( scratch.Output(1,1) ) Then
      GetRecord (scratch_out(1),scratch,1)
      rh_hmp_mean = 100*e_hmp_mean/e_sat_hmp_mean
      DewPoint (t_dew_hmp_mean,t_hmp_mean,rh_hmp_mean)

      'Control the NR 01 heater using 4 Hz pulse width modulation. Below the dew
      'point temperature applies 100% power. Above the dew point, power is reduced
      'linearly to 20% until the dew point plus DELTA_SET_POINT_1. After the dew
      'point plus DELTA_SET_POINT_1 and until the dew point plus
      'DELTA_SET_POINT_2 plus DELTA_SET_POINT_2, the power is reduced linearly to 0%.
      If ( (t_nr01 <> NaN) AND (t_dew_hmp_mean <> NaN) AND (no_heat_flag <> TRUE) ) Then
        set_point_temperature = t_dew_hmp_mean+273.15
        Select Case t_nr01
        Case Is < ( set_point_temperature )
          duty_cycle = 1
        Case Is < ( set_point_temperature+DELTA_SET_POINT_1 )
          duty_cycle = MAX_DUTY_CYCLE_1+(t_nr01-(t_dew_hmp_mean+273.15))*SLOPE_1
        Case Is < ( set_point_temperature+DELTA_SET_POINT_1+DELTA_SET_POINT_2 )
          duty_cycle = MAX_DUTY_CYCLE_2+(t_nr01-
          (t_dew_hmp_mean+273.15+DELTA_SET_POINT_1))*SLOPE_2
        Case Else
          duty_cycle = 0.01
        EndSelect
      Else
        duty_cycle = 0.01
      EndIf
    EndIf

    CallTable (stats)
  NextScan
EndProg
```

# Appendix B. Cable Details

TABLE B-1 provides the polarity and PCB04 connection for Cable 1 (solar), and TABLE B-2 provides the polarity and PCB04 connection for Cable 2 (PT100). TABLE B-3 shows the internal connections to the terminal blocks, which should only be required for servicing such as cable replacement.

**TABLE B-1. Cable 1 (Solar) Polarity and PCB04 Connection**

| Color | Wire Label | Polarity* | PCB04 Connection |
|---|---|---|---|
| Red | Pyranometer Up Sig | + | 2 |
| Blue | Pyranometer Up Ref | – | 1 |
| White | Pyranometer Down Sig | + | 8 |
| Green | Pyranometer Down Ref | – | 7 |
| Brown | Pyrgeometer Up Sig | + | 4 |
| Yellow | Pyrgeometer Up Ref | – | 3 |
| Purple | Pyrgeometer Down Sig | + | 6 |
| Grey | Pyrgeometer Down Ref | – | 5 |
| Clear | Shield | Ground | 11, 12 |

*The + connections of radiometers give + signal when radiation comes in.

**TABLE B-2. Cable 2 (Temperature/Heater) Polarity and PCB04 Connection**

| Color | Wire Label | Polarity | PCB05 Connection |
|---|---|---|---|
| Red* | Current Excite | + | 2 |
| Blue | Current Return | – | 4 |
| White* | PT100 Signal | + | 3 |
| Green | PT100 Signal Ref | – | 5 |
| Brown** | Heater Power SW12V | + | 1 |
| Yellow** | Heater Ground | – | 6 |
| Purple | Ground | GND | 7 |
| Grey | Shield | GND | 8 |
| Clear | Shield | Ground | 9, 10 |

*The red and white end is at same side of the sensor (both +).

**The heater polarity are not critical.

| TABLE B-3.  Internal Electrical Diagram of the NR01 (for servicing purposes only) | | | | |
|---|---|---|---|---|
| **PCB04 Connection** | **PCB04 Terminal** | **PCB05 Connection** | **PCB05 Terminal** | **Polarity** |
| 3 | | 8 | Pyrgeometer UP | – |
| 4 | | 7 | Pyrgeometer UP | + |
| 5 | | 12 | Pyrgeometer DOWN | – |
| 6 | | 11 | Pyrgeometer DOWN | + |
| 13 | Pyranometer UP | | | + |
| 14 | Pyranometer UP | | | – |
| 9 | Pyranometer DOWN | | | + |
| 10 | Pyranometer DOWN | | | – |

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