INSTRUCTION MANUAL

NR01 Four-Component Net Radiation Sensor

Revision: 8/11

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NR01 Table of Contents

PDF viewers note: These page numbers refer to the printed version of this document. Use the Adobe Acrobat® bookmarks tab for links to specific sections.

Figures

Tables

NR01 Four-Component Net Radiation Sensor

The NR01 is a four-component net radiation sensor that is used for scientific-grade energy balance studies.

1. Introduction

The NR01 has separate measurements of solar (Short Wave or SW) and Far Infra-Red (Long Wave or LW) radiation. It offers a professional solution to the measurement of net radiation and its four main components. The NR01 is robust and requires only limited maintenance.

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.

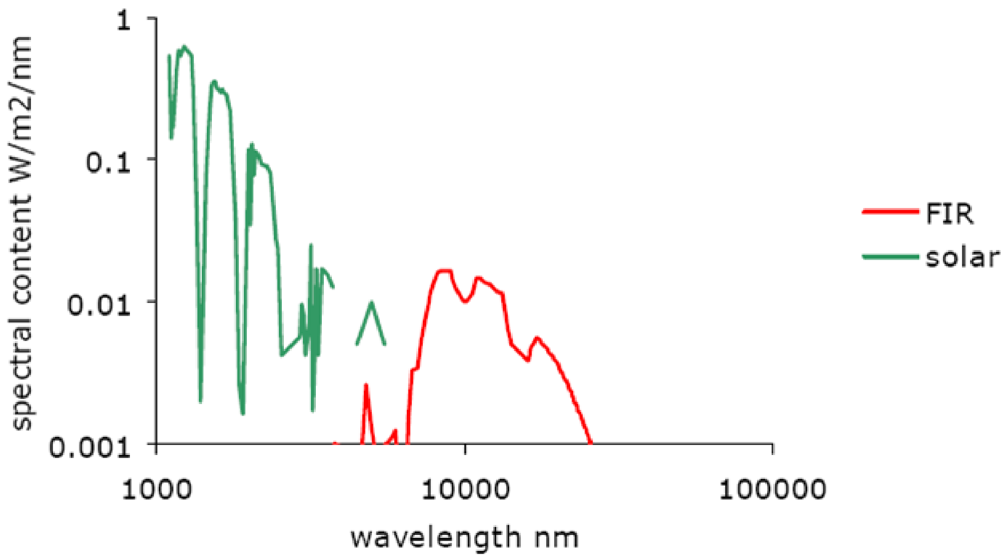

FIGURE 1-1. Atmospheric Radiation as a Function of Wavelength
LW or FIR radiation is mainly present in the 4500 to 50000 nm region, while SW or solar radiation is mainly present in the 300 to 3000 nm region. The two are measured separately.

Major improvements of the NR01 relative to comparable instruments include reduced weight, reduced solar offsets in the LW signal, ease of leveling (because a 2-axis leveling assembly is built-in).

The NR01 serves to measure 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 SW sensors are also called pyranometers (type SR01); the LW sensors are called pyrgeometers (type IR01). For calculation of the sky and surface temperature, a PT100 temperature sensor is included in the connection body of the pyrgeometers. A heater is also included in the pyrgeometers’ connection body to heat the pyrgeometers, which prevents the deposition of dew.

The NR01 requires leveling; a two-axis leveling facility is incorporated in the design. See the chapter on installation.

Using the NR01 is easy. For readout one only needs four analog input channels, and, only if sky and surface temperature are required, a way to measure the PT100. If power is available, Campbell Scientific recommends heating the pyrgeometers from sundown to sunset.

The NR01 is supplied with four separate instrument sensitivities. As a brief explanation, 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. For example:

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

More information can be found in the chapter on instrument performance.

WARNING **The NR01 is a passive sensor, and does not need any power. The NR01 pyrgeometer can, however, be heated to prevent dew-deposition.**

Putting more than 12 Volt across the NR01 sensor wiring can permanently damage the sensor.

2. Measurement Principle

The following chapters explain the measurement principles of the NR01. Pyranometers and pyrgeometers are treated in different paragraphs. The last section is about expected measurement results.

2.1 General

In its most common application, the NR01 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.

$SW_{in} = U_{pyrano, up} / E_{pyrano, up}$ 2.1-1

$SW_{out} = U_{pyrano, down} / E_{pyrano, down}$ 2.1-2

$LW_{in} = (U_{pyrgeo, up} / E_{pyrgeo, up}) + 5.67.10^{-8} (T_{pyrgeo})^4$ 2.1-3

$LW_{out} = (U_{pyrgeo, down} / E_{pyrgeo, down}) + 5.67.10^{-8} (T_{pyrgeo})^4$ 2.1-4

NOTE: in the LW_{net} the instrument temperature is cancelled:

$LW_{net} = U_{pyrgeo, up} / E_{pyrgeo, up} - U_{pyrgeo, down} / E_{pyrgeo, down}$ 2.1-5

$SW_{net} = U_{pyrano, up} / E_{pyrano, up} - U_{pyrano, down} / E_{pyrano, down}$ 2.1-6

$NR = SW_{net} + LW_{net}$ 2.1-7

Special parameters that could be deducted:

$SW\ albedo = SW_{in} / SW_{out}$ 2.1-8

NOTE The following equations assume the temperature is in Kelvin. Add 273.15 to equations 2.1-9 and 2.1-10 for temperature in degree Celsius.

$T_{surface} = (LW_{out} /5.67.10^{-8})^{1/4}$ 2.1-9

$T_{sky} = (LW_{in} /5.67.10^{-8})^{1/4}$ 2.1-10

2.2 NR01 Construction

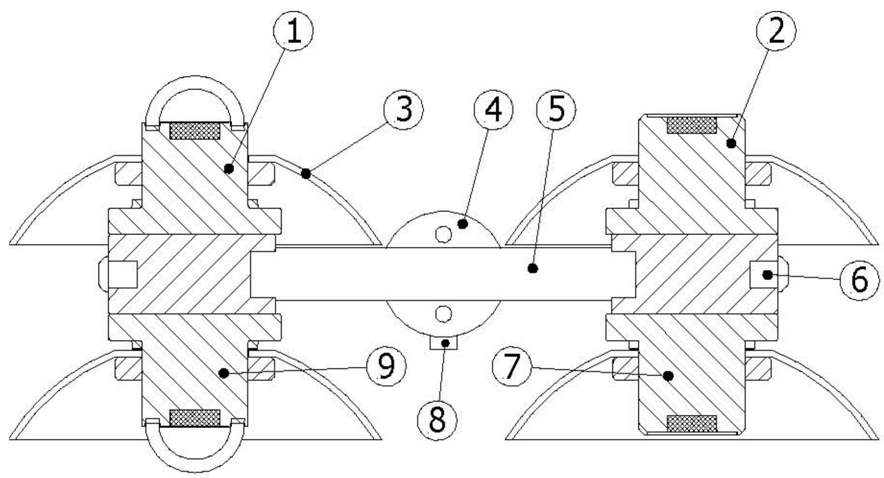

FIGURE 2.2-1. The NR01 Four-Component Net Radiation Sensor

(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.

2.3 Pyranometers

A pyranometer should measure 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. It follows that a 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. Another function of the dome is that it shields the thermopile sensor from convection.

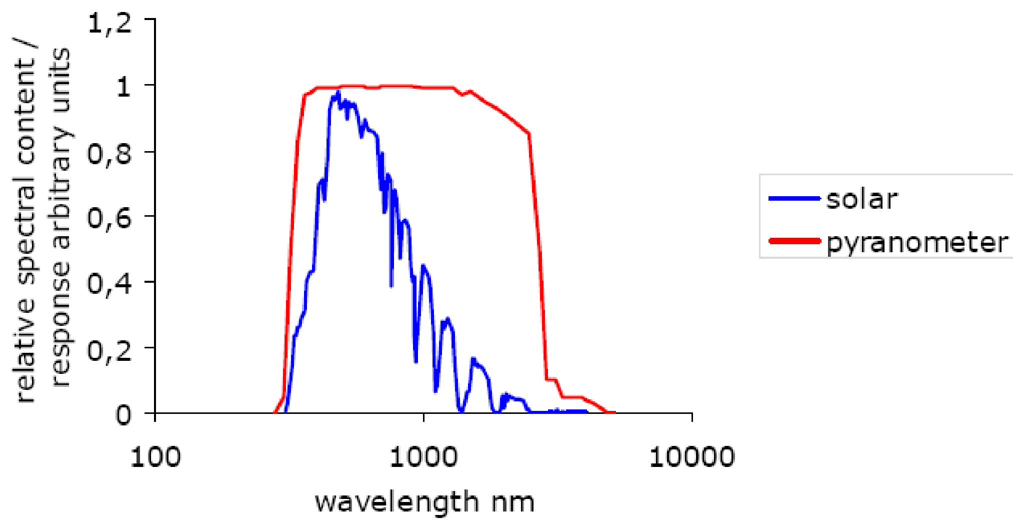

FIGURE 2.3-1. Spectral Response of the Pyranometer Compared to the Solar Spectrum
The pyranometer only cuts off a negligible part of the total solar spectrum.

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.

$$SW_{in} = U_{pyrano,\,up} / E_{pyrano,\,up} \qquad 2.3\text{-}1$$

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 2.3-1 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 2.3-1. 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

2.4 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.

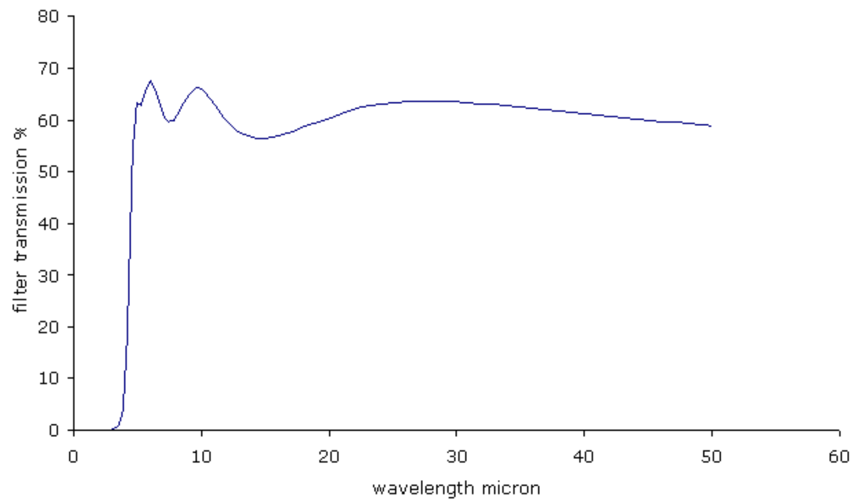

FIGURE 2.4-1. Spectral Response of the Pyrgeometer Compared to the Atmospheric LW Spectrum

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 2.4-1 calculates the incoming LW radiation assuming T_{pyrgeo} is in Kelvin:

$$LW_{in} = (U_{pyrgeo,\ up} / E_{pyrgeo,\ up}) + 5.67.10^{-8}\ (T_{pyrgeo})^{4} \qquad 2.4\text{-}1$$

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 2.4-2 calculates, in Kelvin, the sky temperature:

$$T_{sky} = (LW_{in} / 5.67.10^{-8})^{1/4} \quad 2.4\text{-}2$$

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 2.4-2 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 2.4-2. 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

2.5 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 2.5-1 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 2.5-1. 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 2ºC.
** LW_{out} value assumes a surface temperature of 14ºC.

NOTE The LW radiation values in Table 2.5-1 are corrected for sensor temperature. The values in Table 2.5-2 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 2.5-2. Expected SENSOR Outputs when Measuring with the NR01								
D / N	CD / CR	Ambient air temp.	pyrgeo down#	pyrgeo up#	pyrano down	pyrano up	T_{sky}	T_{ground}
		°C	W/m^2	W/m^2	W/m^2	W/m^2	°C	°C
D	CD	+20	0	0	0-500	0-150	20	+20
D	CD	-20	0	0	0-500	0-150	-20	-20
D	CR	+20	-70**	0	0-1500	0-400	+1	+20
D	CR	-20	-70**	0	0-1500	0-400	-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

The 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 instrument temperature is normally close to air temperature.

#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 ºC, you should add 385 W/m^2 to the pyrgeometer signals. The raw reading of the upward facing pyrgeometer will generally be close to zero when the sensor temperature is close to the ground temperature. You should expect small negative readings when the sensor is located above cooled surfaces (e.g. water or transpiring vegetation) or small positive readings when the surface is emitting heat (e.g. warm soil at night).

* At night, dew deposition may affect the downward facing pyrgeometer's output. In that case, the signal may drop to 0 W/m^2, producing a maximum error of +100 W/m^2. 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/m^2.

***At night, the infrared offset may affect the downward facing pyranometer's output. The maximum error of this offset is -25 W/m^2.

2.6 Heating

A heater is located in the connection body of the pyrgeometers to prevent dew deposits on the sensor that may occur at night. Because of the heater's current drain, Campbell Scientific recommends using the heater only when necessary. A relay can turn the heater on when the solar radiation is less than 20 W/m^2. See Section 4.3.1.

2.7 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

3. Specifications of NR01

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.

3.1 NR01 General Specifications

TABLE 3.1-1. General Specifications of the NR01	
ISO and WMO classification	See pyranometer and pyrgeometer specification
Expected accuracy	+/- 10 % for 12 hour totals, day and night
Operating temperature	-40 to +80 ° C
Pyranometer	Type SR01, see below
Pyrgeometer	Type IR01, see below
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 Watts at 12 VDC; 16 V DC Max
2 axis leveling assembly	Included, hexagon drive set screw size 2.0mm, pipe size ¾ inch NPS
Radiation shields	4 shields are included
Cable gland	Accepts cable diameter from 3 to 6.5 mm
Cable extension	Longer cables are available on request. Specify additional cable length in feet (up to 50 ft can be added)
Standard cable length / diameter	50 ft / 5.4 mm (2 cables)
Weight including 5 m cable	NR01 including 50ft cable: 5.0 lbs. NR01 instrument only 2.0 lbs
Dimensions	263 x 113 x 121 mm
Recommended recalibration interval	Every 2 years
CE compliance	NR01 is compliant with CE directives.

3.2 SR01 Pyranometer Specifications

TABLE 3.2-1. Specifications of SR01	
SR01 ISO / WMO Specifications	
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 degrees C)	Within 6% (-10 to +40 degrees C)
Tilt response	Within +/- 2%
SR01 Additional Measurement Specifications	
Sensitivity	10-40 $\mu V/Wm^{-2}$
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	
Calibration traceability	To WRR, procedure according to ISO 9847

3.3 IR01 Pyrgeometer Specifications

TABLE 3.3-1. Specifications of IR01

IR01 Specifications	
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 degrees C)	Within 6% (-10 to +40 degrees C)
Tilt response	Within +/- 2%
IR01 Additional Measurement Specifications	
Sensitivity	5 – 15 $\mu V/Wm^{-2}$
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) $\Phi = (U / E) + 5.67.10^{-8} T^4$ (absolute radiation), with T from Pt100 measurement
Expected accuracy for daily sums	+/- 10%
Calibration	
Calibration traceability	International temperature standard

3.4 Dimensions

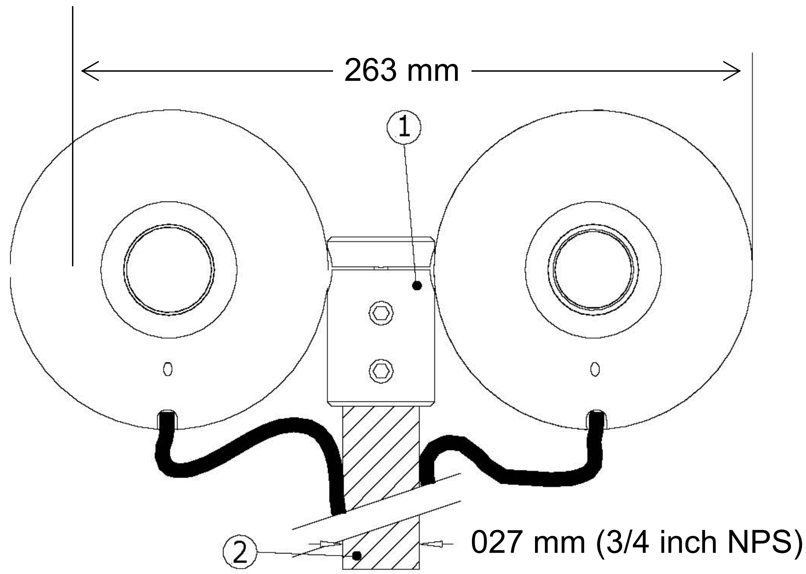

FIGURE 3.4-1. Dimensions of the NR01 in mm: (1) 2-Axis Leveling Assembly, (2) Mounting Arm

4. Installation

4.1 Installation

A 1” to ¾” pipe reducer fitting (P/N 21271) is used 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.

To attach the pipe reducer to the sensor, loosen the leveling assembly’s Allen bolts (8 in Figure 2.2-1). Insert the pipe reducer inside of the cup in the center of the sensor (see Figure 4.1-1) and then tighten the Allen bolts so that they grip the pole. Slightly loosen the two bolts at the opposite end of the tube mount (4 in Figure 2.2-1) 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 4.1-1 gives other general guidelines for the positioning and installation of the sensor.

FIGURE 4.1-1. NR01 with Reducer (P/N 21271) and Mounting Arm

TABLE 4.1-1. 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 27 mm or ¾ inch NPS.
Radiation detection	Avoid objects that cast shadows on the instrument.
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 (so 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 meters) 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.

4.2 Electrical Connections

The NR01 is a passive sensor that does not need any power. However there is an on-board heating resistor in the pyrgeometer connection body that may be switched on to prevent dew deposition.

Cables generally act as a source of signal distortion by picking up capacitively coupled noise. Campbell Scientific generally recommends keeping the distance between the datalogger and sensor as short as possible. For cable extension, see Appendix A. Table 4-2 provides the electrical connections of the NR01.

Cable 1 (Solar)

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

Cable 2 (Temperature/Heater)

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

NOTES:

(1) + connections of radiometers give + signal when radiation comes in.
(2) Pt100 red and white end at same side of the sensor (both +)
(3) Pt100 and heater polarity are not critical.

TABLE 4.2-1. 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			-

Table 4-2 shows the NR01 wiring connections for the four radiation outputs, Pt-100 temperature sensor, and the heater. Table 4.2-1 shows the internal connections to the terminal blocks, which should only be required for servicing, e.g. cable replacement.

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.**

4.3 Connecting the Sensor to Campbell Scientific Dataloggers

This section shows the typical connection schemes.

The four radiation outputs can be measured using Differential (Table 4.3-1) or Single-Ended inputs on the datalogger (Table 4.3-2). A differential voltage measurement (VoltDiff or Instruction 2) 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 AG or ⏚ to keep the signal within the common mode range.

TABLE 4.3-1. Datalogger Connections for Differential Measurement, when using a 4WPB100

Wire Label	Color (cable 1)	CR10X	CR1000, CR23X, CR7
Pyranometer Up Sig	Red	Differential Input (H)	Differential Input (H)
Pyranometer Up Ref	*Blue	Differential Input (L)	Differential Input (L)
Pyranometer Down Sig	White	Differential Input (H)	Differential Input (H)
Pyranometer Down Ref	*Green	Differential Input (L)	Differential Input (L)
Pyrgeometer Up Sig	Brown	Differential Input (H)	Differential Input (H)
Pyrgeometer Up Ref	*Yellow	Differential Input (L)	Differential Input (L)
Pyrgeometer Down Sig	Purple	Differential Input (H)	Differential Input (H)
Pyrgeometer Down Ref	*Grey	Differential Input (L)	Differential Input (L)
Shield	Shield	G	⏚

*Jumper to AG or ⏚ with user supplied wire.

TABLE 4.3-2. Datalogger Connections for Single-Ended Measurement, when using a 4WPB100

Wire Label	Color (Cable 1)	CR10X	CR1000, CR23X, CR7
Pyranometer Up Sig	Red	Single-Ended Input	Single-Ended Input
Pyranometer Up Ref	Blue	AG	⏚
Pyranometer Down Sig	White	Single-Ended Input	Single-Ended Input
Pyranometer Down Ref	Green	AG	⏚
Pyrgeometer Up Sig	Brown	Single-Ended Input	Single-Ended Input
Pyrgeometer Up Ref	Yellow	AG	⏚
Pyrgeometer Down Sig	Purple	Single-Ended Input	Single-Ended Input
Pyrgeometer Down Ref	Grey	AG	⏚
Shield	Shield	G	⏚

All dataloggers apart from the CR3000 and CR5000 require the 4WPB100 module to interface the PT-100 to the datalogger. Table 4.3-3 shows the wiring connections for the 4WPB100 (note this is using cable 2).

TABLE 4.3-3. Pt-100 Temperature Sensor Connections to 4WPB100 and Datalogger

Wire Label	Color (Cable 2)	4WPB100	Datalogger
		Black Wire	Voltage Excitation (VX)
		H	Differential Input (H)
Current Excite	Red	L	Differential Input (L)
Current Return	Blue	G	⏚ (AG CR10X)
PT100 Signal	White		Differential Input (H)
PT100 Signal Ref	Green		Differential Input (L)

The PT-100 sensor can connect directly to the CR3000 and CR5000 dataloggers because they have current excitation outputs. Refer to Table 4.3-4 and Program Example 5.2.2 for information on using the current excitation technique with a CR3000 or CR5000 datalogger.

TABLE 4.3-4. CR3000 and CR5000 Connections for Differential Measurement and using the Current Excitation to Measure the PT100 Sensor

Wire Label	Color	CR3000/CR5000
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)
PT100 Signal	**White	Differential Input (H)
PT100 Signal Ref	**Green	Differential Input (L)
Current Excite	**Red	Current Excitation IX
Current Return -	**Blue	Current Excitation IXR
Shield (both cables)	Clear	⏚

*Jumper to AG or ⏚ with user-supplied wire.
**Note these are in Cable 2.

4.3.1 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 12V 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 dew point of the air falls to within 1ºC of the sensor body temperature. Appendix A provides an example CR3000/CR5000 program that controls the NR01 heater.

4.4 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.

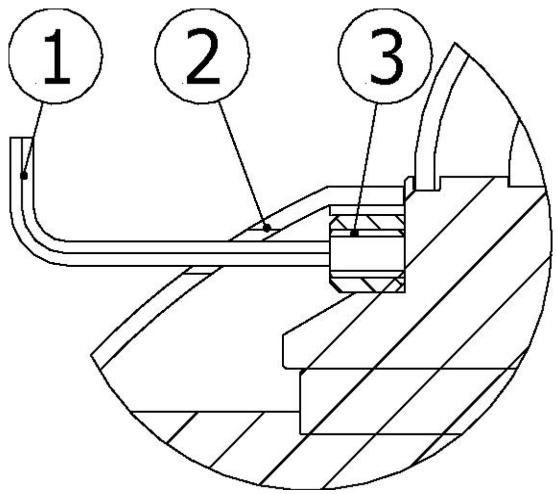

FIGURE 4.4-1. Installation and Removal of Radiation Shields: (1) Hex-Head Wrench, (2) Radiation Screen (3) Hexagon Drive Set Screw

4.5 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).

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

5. Datalogger Programming

The NR01 outputs four voltages that typically range from 0 to 50 mV for the SR01 sensors, and ±5 mV for the IR01 sensors. A differential voltage measurement (VoltDiff in CRBasic or Instruction 2 in Edlog) is recommended because it has better noise rejection than a single-ended measurement. If differential channels are not available, a single-ended measurement (VoltSE or Instruction 1) can be used. The acceptability of a single-ended measurement can be determined by simply comparing the results of single-ended and differential measurements made under the same conditions.

For the CR3000 and CR5000 dataloggers, one differential channel and a current excitation channel are used to measure the PT-100.

For the other dataloggers, two differential channels and the 4WPB100 module are required to measure the Pt-100 temperature sensor.

FIGURE 5-1. 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.

5.1 Calibration Factors

Each NR01 is provided with a ‘Certificate of Calibration’ by the manufacturer. This certificate shows the sensor serial number and ‘sensitivity’ of each of the four component sensors. Unlike some other models of sensor, the individual components are not modified in an attempt to have a common calibration. Therefore, individual calibration factors 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 uV/(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 uV/(W m^{-2}), the multiplier is 1000/7.3 = 136.99 (W m^{-2})/mV.

5.2 Example Programs

5.2.1 Example 1, CR1000 Using Differential Channels

Program Example 1 requires six differential channels and the 4WPB100 module to measure the four radiation outputs and the Pt-100 temperature sensor, connected on differential channels 1..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.

Pt-100 Temperature Sensor Connections to 4WPB100 and Datalogger

Color	Function	4WPB100	CR1000
Black		Wire	EX1
		H	5H
Red	Pt-100 Excitation +	L	5L
Blue	Pt-100 Excitation -	G	⏚
White	Pt-100 Signal +		6H
Green	Pt-100 Signal -		6L

```
'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 uV/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 loggers use:

* mV50 range for the CR3000/5000

** mV50 range (both) with 4200 mV excitation for CR3000/5000

5.2.2 Example 2, CR3000/CR5000 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 Pt-100 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

```
'CR3000 or CR5000 Series 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.

5.2.3 Example 3, CR23X Program Using Differential Channels

Program Example 3 requires six differential channels and the 4WPB100 module to measure the four radiation outputs and the Pt-100 temperature sensor. Wiring is shown in Tables 4.3-1 and 4.3-3 above, using differential channels 1..5. The program measures the sensors every 2 seconds, then calculates and stores the following data to final storage every 60 minutes:

Array ID
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

```
;{CR23X}
;Program Example 3 for CR23X datalogger
;
;*Table 1 Program
  01:  2               Execution Interval (seconds)

;Measure all four sensor elements with one instruction, use auto-ranging  for best resolution
1:  Volt (Diff) (P2)
  1:   4               Reps
  2:   30              Auto, 50 Hz Reject, Slow Range (OS>1.06)
  3:   1*              DIFF Channel
  4:   1               Loc [ SR01_up   ]
  5:   1.0             Multiplier
  6:   0.0             Offset

;Apply the individual calibration factors to each component
;with one scaling  instruction

;Typical data on the data sheet might be
;Sensor                     Sensitivity uV/W/m^2
;Pyranometer UP   SR01      15.35
;Pyranometer DOWN SR01      13.30
;Pyrgeometer UP   IR01      8.5
;Pyrgeometer DOWN IR01      8.2

; Multipliers calculated at 1000/sensitivity
2:  Scaling Array (A*Loc+B) (P53)
  1:   1               Start Loc [ SR01_up   ]
  2:   65.146          A1                          ;SR01 up
  3:   0               B1
  4:   75.18           A2                          ;SR01 down
  5:   0.0             B2
  6:   117.65          A3                          ;IR01 up
  7:   0.0             B3
  8:   121.95          A4                          ;IR01 down
  9:   0.0             B4

;Measure NR01 temperature

3:  Full Bridge w/mv Excit (P9)
  1:   1               Reps
  2:   32**            50 mV, 50 Hz Reject, Slow, Ex Range
  3:   32**            50 mV, 50 Hz Reject, Slow, Br Range
  4:   5*              DIFF Channel
  5:   1               Excite all reps w/Exchan 1
  6:   4200***         mV Excitation
  7:   5*              Loc [ Temp_C    ]
  8:   1               Mult
  9:   0               Offset
```

```
4:  Temperature RTD (P16)
   1:   1              Reps
   2:   5              R/R0 Loc [ Temp_C    ]
   3:   5              Loc [ Temp_C    ]
   4:   1.0            Mult
   5:   0              Offset

5:  Z=X+F (P34)
   1:   5              X Loc [ Temp_C    ]
   2:   273.18         F
   3:   6              Z Loc [ Temp_K    ]

;Net SR01 shortwave radiation = SR01 Up - SR01 Down

6:  Z=X-Y (P35)
   1:   1              X Loc [ SR01_up    ]
   2:   2              Y Loc [ SR01_dn    ]
   3:   7              Z Loc [ Net_Rs    ]

;Net IR01 longwave radiation = IR01 Up - IR01 Down

7:  Z=X-Y (P35)
   1:   3              X Loc [ IR01_up    ]
   2:   4              Y Loc [ IR01_dn    ]
   3:   8              Z Loc [ Net_Rl    ]

;Albedo = SR01 Down / SR01 Up

8:  Z=X/Y (P38)
   1:   2              X Loc [ SR01_dn    ]
   2:   1              Y Loc [ SR01_up    ]
   3:   9              Z Loc [ Albedo    ]

;Net total radiation = (SR01 Up + IR01 Up) - (SR01 Down + IR01 Down)

9:  Z=X+Y (P33)
   1:   1              X Loc [ SR01_up    ]
   2:   3              Y Loc [ IR01_up    ]
   3:   23             Z Loc [ Up_total  ]

10:  Z=X+Y (P33)
   1:   2              X Loc [ SR01_dn    ]
   2:   4              Y Loc [ IR01_dn    ]
   3:   24             Z Loc [ Dn_total  ]

11:  Z=X-Y (P35)
   1:   23             X Loc [ Up_total  ]
   2:   24             Y Loc [ Dn_total  ]
   3:   10             Z Loc [ Net_total ]

;Correct IR01 Up and IR01 Down for temperature
```

```
; IR01_upCor = IR01_up+5.67  10-8. Temp_K4
; IR01_dnCor = IR01_dn+5.67  10-8. Temp_K4

12:  Z=F (P30)
   1:   5.67           F
   2:   -8             Exponent of 10
   3:   25             Z Loc [ scratch_1 ]

13:  Z=F (P30)
   1:   4              F
   2:   0              Exponent of 10
   3:   26             Z Loc [ scratch_2 ]

14:  Z=X^Y (P47)
   1:   6              X Loc [ Temp_K    ]
   2:   26             Y Loc [ scratch_2 ]
   3:   27             Z Loc [ scratch_3 ]

15:  Z=X*Y (P36)
   1:   25             X Loc [ scratch_1 ]
   2:   27             Y Loc [ scratch_3 ]
   3:   28             Z Loc [ scratch_4 ]

16:  Z=X+Y (P33)
   1:   3              X Loc [ IR01_up    ]
   2:   28             Y Loc [ scratch_4 ]
   3:   11             Z Loc [ IR01_upCor ]

17:  Z=X+Y (P33)
   1:   4              X Loc [ IR01_dn    ]
   2:   28             Y Loc [ scratch_4 ]
   3:   12             Z Loc [ IR01_dnCor ]
;
;Output data to final storage every 60 minutes

18:  If time is (P92)
   1:   0              Minutes (Seconds --) into a
   2:   60             Interval (same units as above)
   3:   10             Set Output Flag High (Flag 0)

19:  Real Time (P77)
    1:  0220           Day,Hour/Minute (midnight = 2400)

20:  Average (P71)
   1:   12             Reps
   2:   1              Loc [ SR01_dn    ]
```

Note: Proper entries will vary with program and *input channel usage. For other loggers use:
** 25 mV range for CR10X, 50 mV for 21X and CR7
*** 4200 mV for 21X and CR7, 2100 mV for CR10X

5.2.4 Example 4, CR23X Program Using Single-Ended Channels

Program Example 4 requires four single-ended channels to measure the four radiation outputs, and four single-ended channels and one differential channel for the 4WPB100 module to measure the Pt-100 temperature sensor. Wiring is as in Table 4.3-2, using SE channels 1..4 and 4.5 above using differential channel 3 and 4 for the PT100 sensor. The program measures the sensors every 2 seconds, then stores the following data to final storage every 60 minutes:

Array ID
Year
Day
Hour/Minute
Avg SR01 down (shortwave radiation)
Avg SR01 up (shortwave radiation)
Avg IR01 down (longwave radiation)
Avg IR01 up (longwave radiation)
Avg NR01 temperature (degrees C)
Avg NR01 temperature (degrees K)

```
;{CR23X}
;Example for SE measurements of the NR01 using a CR23X
;
*Table 1 Program
  01: 2              Execution Interval (seconds)

;Measure all four sensor elements with one instruction, use auto-ranging for best resolution
1:  Volt (SE) (P1)
  1:   4             Reps
  2:   30            Auto, 50 Hz Reject, Slow Range (OS>1.06)
  3:   1*            SE Channel
  4:   1             Loc [ SR01_up   ]
  5:   1.0           Multiplier
  6:   0.0           Offset

;Apply the individual calibration factors to each component
;with one instruction

;Typical data on the data sheet might be
;Sensor                      Sensitivity uV/W/m^2
;Pyranometer UP   SR01       15.35
;Pyranometer DOWN SR01       13.30
;Pyrgeometer UP   IR01       8.5
;Pyrgeometer DOWN IR01        8.2

; Multipliers calculated at 1000/sensitivity
```

```
2:  Scaling Array (A*Loc+B) (P53)
   1:   1              Start Loc [ SR01_up   ]
   2:   65.146         A1                          ;SR01 up
   3:   0              B1
   4:   75.18          A2                          ;SR01 down
   5:   0.0            B2
   6:   117.65         A3                          ;IR01 up
   7:   0.0            B3
   8:   121.95         A4                          ;IR01 down
   9:   0.0            B4

;Measure the IR01 temperature

3:  Full Bridge w/mv Excit (P9)
   1:   1              Reps
   2:   32             50 mV, 50 Hz Reject, Slow, Ex Range**
   3:   32             50 mV, 50 Hz Reject, Slow, Br Range**
   4:   3*             DIFF Channel
   5:   1              Excite all reps w/Exchan 1
   6:   4200           mV Excitation***
   7:   5              Loc [ IR01_TC   ]
   8:   1              Multiplier
   9:   0.0            Offset

4:  Temperature RTD (P16)
   1:   1              Reps
   2:   5              R/R0 Loc [ IR01_TC   ]
   3:   5              Loc [ IR01_TC   ]
   4:   1.0            Multiplier
   5:   0.0            Offset

;Also create a temperature in K for use in optional online
;calculation of fluxes
5:  Z=X+F (P34)
   1:   5              X Loc [ IR01_TC   ]
   2:   273.15         F
   3:   6              Z Loc [ IR01_TK   ]

;In this example just output the scaled flux measurements
6:  If time is (P92)
   1:   0              Minutes (Seconds --) into a
   2:   60             Interval (same units as above)
   3:   10             Set Output Flag High (Flag 0)

7:  Real Time (P77)
   1:   0220           Day,Hour/Minute (midnight = 2400)

8:  Average (P71)
   1:   6              Reps
   2:   1              Loc [ SR01_up   ]
```

Note: Proper entries will vary with program and *input channel usage. For other loggers use:
**   25 mV range for CR10X, 50 mV for 21X and CR7
*** 4200 mV for 21X and CR7, 2100 mV for CR10X

6. Maintenance and Troubleshooting

6.1 Maintenance

Once installed the NR01 is essentially maintenance free apart from cleaning dirt off the domes every few weeks. Usually errors in functionality will appear as unreasonably large or small measured values.

As a general rule, this means that a critical review of the measured data is the best form of maintenance.

At regular intervals the quality of the cables can be checked.

On a 2 yearly interval the calibration can be checked in an indoor facility.

TABLE 6.1-1. The NR01 Recommendations for Maintenance
Critical review of data
Cleaning of dome using water or alcohol
Inspection of dome interior; no condensation
Inspection of cables for open connections
For the NR01: sensor inversion test as in 4.5.
Recalibration: suggested every 2 years, typically by intercomparison with a higher standard in the field.

6.2 Troubleshooting

This table contains information used to diagnosis problems whenever the sensor does not function properly.

TABLE 6.2-1. 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. In case of open circuits: open the instrument and check the internal connections (see wiring diagram of Table 4.2-1.)
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. Check if the voltage reading is divided by the calibration factor by review of the algorithm. Check the condition of the leads at the logger. Check the cabling condition looking for cable breaks. Check the data acquisition by applying an mV source to it in the 1 mV range. Perform a sensor-inversion test as written down in 4.5. Open the instrument and check the internal connections (see wiring diagram of Table 4.2-1).
The sensor signal shows unexpected variations	Check the presence of strong sources of electromagnetic radiation (radar, radio etc.) Check the condition of the shielding. Check the condition of the sensor cable. Open the instrument and check the internal connections (see wiring diagram of Table 4.2-1).

Appendix A. CR3000 Program that Controls the 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 degrees C as a set point for the heater, the program below uses the dew point value. The datalogger calculates dew point using the relative humidity (RH) measurements provided by the HMP45C Temperature/Relative Humidity probe. Enter 0 degrees 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 dew point temperature. At or below the dew point, the duty cycle is 100%. It drops off linearly to 20% until the body temperature is 5 degrees C above the dew point. For body temperatures greater than 5 degrees C above the dew point, the duty cycle continue to drop linearly, but with a different slope, until 0% at 33 degrees C above the dew point. If necessary, the user can change the two duty-cycle slope transitions.

```
'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
'C1      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
```

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