SR11

First Class Solar Radiation Sensor

SR11 manual v0704

Hukseflux Thermal Sensors
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Hukseflux
Thermal Sensors

Warning:

Warnings and safety issues

SR11 is a passive sensor, and does not need any power.

Putting more than 12 Volt across SR11 sensor wiring can lead to permanent damage to the sensor.

Contents

List of symbols

Voltage output	U	μV
Sensitivity of the SR11	E	$\mu V/Wm^{-2}$
Time	t	s
Response time	τ	s
Temperature	T	°C
Differential temperature	ΔT	K
Electrical resistance / impedance	R_e	Ω
Solar irradiance	Φ	W/m^2
Wavelength of radiation	n	nm
Radiation sum	S	J/ m^2
Directional error	-	%

Subscripts

sen	sensor property
sh	shunt resistor
new	property after modification

Introduction

SR11 is a solar radiation sensor that can be applied in scientific grade solar radiation observations. It complies with the “first class” specifications within the latest ISO and WMO standards. The scientific name of this instrument is pyranometer.

SR11 serves to measure the solar radiation flux that is incident on a plane surface in W/m^2 from a 180 degrees field of view (also called “global” solar radiation). Working completely passive, using a thermopile sensor, SR11 generates a small output voltage proportional to this flux.
Employing two glass domes, certain measurement errors are reduced; in particular thermal offsets, so that a high measurement accuracy can be attained.
Using SR11 is easy. For readout one only needs an accurate voltmeter that works in the millivolt range. To calculate the radiation level the voltage must be divided by the sensitivity; a constant that is supplied with each individual instrument. SR11 can directly be connected to most commonly used datalogging systems.
SR11 can be used for scientific meteorological observations, building physics, climate- and solar collector testing. A common application is for outdoor solar radiation measurements as part of a meteorological station. This application requires horizontal levelling; levelling feet (7) and a level (11) are included. The SR11 cable can easily be installed or replaced by the user.
Applicable standards are ISO 9060 and 9847, WMO (World Meteorological Organisation), and ASTM E824-94. SR11 can also be used for stability estimations according to EPA (EPA-454/R-99-005).

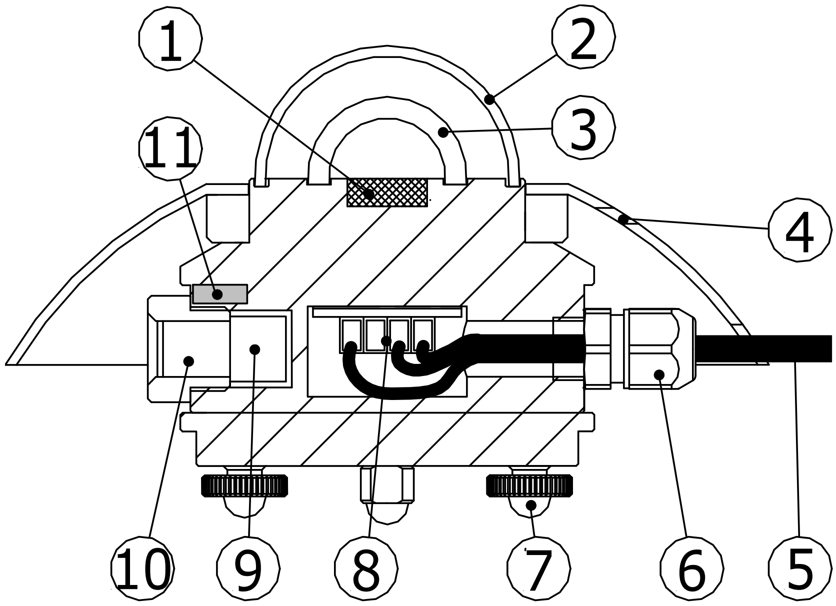

Figure 1 *SR11 solar radiation sensor. (1) sensor, (2, 3) glass domes, (4,5) radiation screen, (6) dessicant, (7,9) levelling feet, (8) printed circuit board, (10) cable gland, (11) cable, (12) level, standard length 5 m.*

1 Checking at delivery

Arriving at the customer, the delivery should include:

- pyranometer SR11
- cable of the length as ordered
- calibration certificate matching the instrument serial number
- hex head wrench 2.5 mm to remove caps
- any other options as ordered

It is recommended to store the certificate in a safe place.

Testing the instrument can be performed by using a simple hand held multimeter.

1 Check the impedance of the sensor between the green (-) and white (+) wire. Use a multimeter at the 200 ohms range. Measure at the sensor output first with one polarity, than reverse polarity. Take the average value. The typical impedance of the wiring is 0.1 ohm/m. Typical impedance should be the typical sensor impedance of 40-60 ohms plus 1.5 ohm for the total resistance of two wires (back and forth) of each 5 meters. Infinite indicates a broken circuit; zero indicates a short circuit.
2 Check if the sensor reacts to light: put the multimeter at its most sensitive range of DC voltage measurement, typically 100 microvolt range or lower.
3 expose the sensor to strong light source, for instance a 100 Watt light bulb at 10 centimeter distance. The signal should read several millivolts now
4 darken the sensor either by putting something over it or switching off the light. The instrument voltage output should go down and within one minute approach zero mV.

More detailed installation directions and trouble shooting directions can be found in the following chapters

The programming of data loggers is the responsibility of the user. Please contact the supplier to see if directions for use with your system are available.
Please contact the supplier to see if directions for use with your system are available. In case programming for similar instruments is available, this can typically also be used.

2 Instrument principle

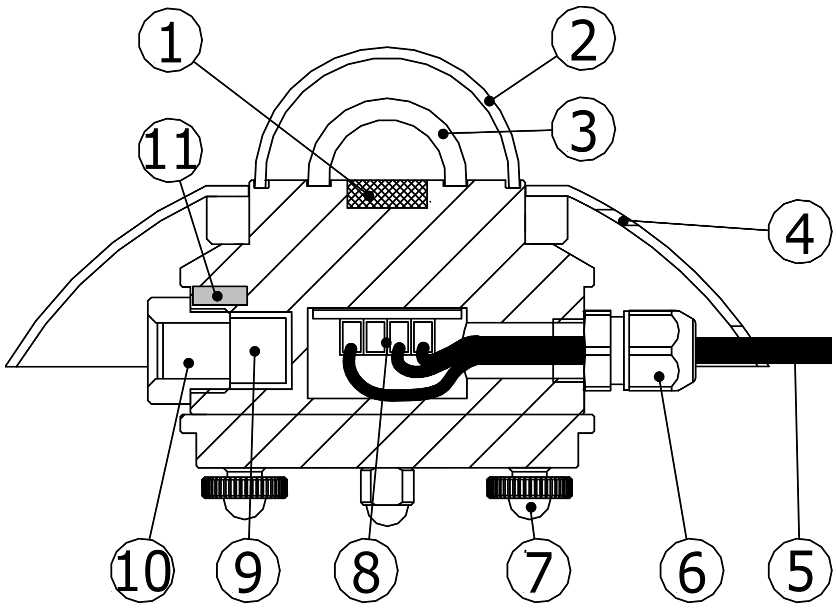

Figure 2.1: *Copy of Figure 0.1 SR11 solar radiation sensor:*
(1) thermopile sensor with black coating
(2) outer glass dome
(3) inner glass dome
(4) radiation shield (metal ring)
(5) radiation shield
(6) dessicant
(7) levelling feet (screwed)
(8) printed circuit board with connector block
(9) levelling foor fixed
(10) cable gland
(11) cable, standard length 5m or longer as ordered

SR11's scientific name is pyranometer. A pyranometer is supposed to measure the solar radiation flux from a field of view of 180 degrees.
The solar radiation spectrum extends roughly from 300 to 2800nm. 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; i.e. full response at when the solar radiation hits the sensor perpendicularly (normal to the surface, sun at zenith,

0 degrees angle of incidence), zero response when the sun is at the horizon (90 degrees angle of incidence, 90 degrees zenith angle), and 0.5 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. a thermopile sensor with a black coating. This sensor absorbs all solar radiation, has a flat spectrum covering the 300 to 50000 nanometer range, and has a near-perfect cosine response.
2. a glass dome. This 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.
3 a second glass dome: For a first class pyranometer, two domes are used, and not one single dome. This construction provides a "thermal shield", so that there is a better thermal equilibrium between the sensor and inner dome, compared to using a single dome. The effect is a strong reduction of instrument offsets.

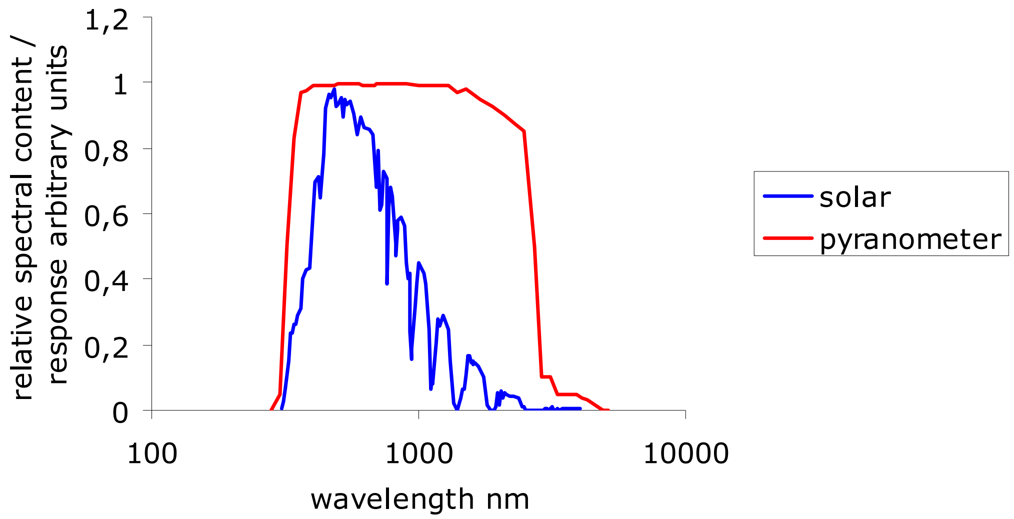

Figure 2.2 *spectral response of the pyranometer compared to the solar spectrum. The pyranometer only cuts off a negligible part of the total solar spectrum*

TO BE ADDED WHEN AVAILABLE

Figure 2.3 *cosine response of a typical SR11 compared to the limits allowed for first class pyranometers in the ISO 9060 standard and to the maximum tolerance as specified for SR11*

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 SR11 housing. The thermopile sensor generates a voltage output signal that is proportional to the solar radiation.

3 Specifications of SR11

SR11 serves to measure the solar radiation flux that is incident on a plane surface in W/m^2 from a 180 degrees field of view (also called global solar radiation). Working completely passive, using a thermopile sensor, SR11 generates a small output voltage proportional to this flux. It can only be used in combination with a suitable measurement system.

SR11 ISO / WMO Specifications	
Overall classification according to ISO 9060 / WMO	First 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	< +/- 1 % (100 to 1000 W/m^2)
Directional response for beam radiation:	Within +/- 20 W/m^2
Spectral selectivity	+/- 5% (305 to 2000 nm)
Temperature response (within an interval of 50 degrees C)	Within 4% (-10 to +40 degrees C)
Tilt response	Within +/- 2%

Table 3.1 *Specifications of SR11 (continued on the next page)*

SR11 ADDITIONAL MEASUREMENT SPECIFICATIONS	
Sensitivity	10-40 μV/Wm^{-2}
Expected voltage output	Application with natural solar radiation: -0.1 to + 50 mV
Operating temperature	-40 to +80 °C
Sensor resistance	Between 40 and 60 Ohms (without trimming)
Power required	Zero (passive sensor)
Standard cable length / diameter	5 meters / 5 mm
Cable gland	Accepts cable diameter from 3 to 6.5 mm
Range	To 2000 Wm^{-2}
Cable replacement	Cable can be removed and installed by the user
Spectral range	305 to 2800 nm (50% transmission points)
Required readout:	1 differential voltage channel or 1 single ended voltage channel
Levelling	Level and levelling feet included
Drying cartridge/ humidity indicator	Type A1, bijlbarneveld.com, recycling temperature 120 deg C, dim 10 by 12 (diameter) mm. Humidity indicatior B2.
Required programming	$\Phi = U / E$
Expected accuracy for daily sums	+/- 5%
Weight including 5 m cable	0.75 kg, packaging weight 1 kg box 20x13.5x22.5 cm
CALIBRATION	
Calibration traceability	To WRR, procedure according to ISO 9847
Recommended recalibration interval	Every 2 years
OPTIONS	
Sensitivity adaptation	As an option the circuit board inside SR11 can be delivered with soldering pins, making it possible to add trimming resistors to adapt the SR11 sensitivity
Cable extension	Longer cables can be supplied on request. Specify additional cable length x meters (add to 5 m)
Amplifiers	AC100 and AC 420
Hand Held Readout	LI18

Table 3.1 *Specifications of SR11 (started on the previous page)*

4 Installation

4.1 Installation

SR11 is usually installed horizontally, but can also be installed on a tiled plane or even in an inverted position.

In all cases it will measure the flux that is incident on the surface that is parallel to the sensor surface.

Mechanical mounting	Preferably use holes in the instrument bottom
Radiation detection	It should be avoided that there are objects between the course of the sun and the instrument, casting shadows on the instrument.
Levelling	Use the included level if mounted horizontally. For viewing the level, the radiation screens must be removed.
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 1.5 meters above ground is recommended by WMO (to get good spatial averaging)
Tilt	SR11 is usually installed horizontally, but for some applications it may be installed in a tilted or inverted position. In all cases it will measure the fluxes that are incident on the surface that is parallel to the sensor surface.

Table 4.1.1 *recommendations for installation of SR11*

In case that refelcetd radiation needs to be measured, a tyical setup is drawn in the figure below.

TO BE INSERTED WHEN AVAILABLE

Figure 4.1.1 *SR11's mounted back to back for measurement of reflected radiation.*

4.2 Electrical connection

In order to operate, SR11 should be connected to a measurement system, typically a so-called datalogger.
SR11 is a passive sensor that does not need any power.
Cables generally act as a source of distortion, by picking up capacitive noise. It is a general recommendation to keep the distance between data logger or amplifier and sensor as short as possible. For cable extension, see the appendix on this subject.

Wire	Colour	Measurement system
Sensor output +	White	Voltage input +
Sensor output -	Green	Voltage input - or ground
Shield		Analogue ground

Table 4.2.1 *The electrical connection of SR11.*

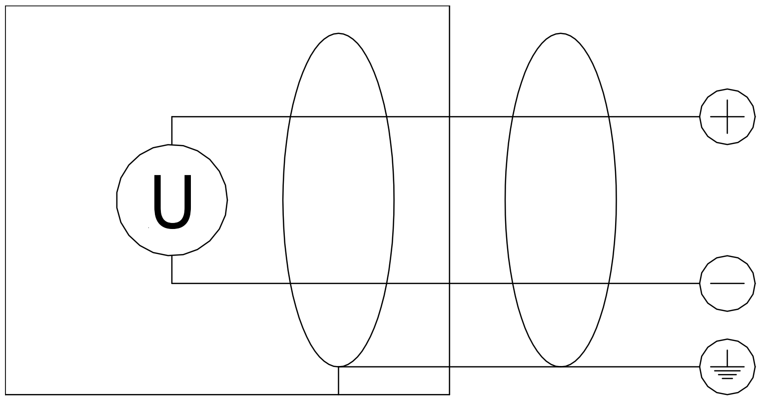

Figure 4.2.1 *Electrical diagram of SR11.*

Sensor	Printed Circuit	Colour code wire
Plus (+)	+	White
Minus (-)	-	Green
Shield	SH	Wire shield
	TR	Not connected

Table 4.2.2 *Standard internal connection of SR11 at the connector block.*

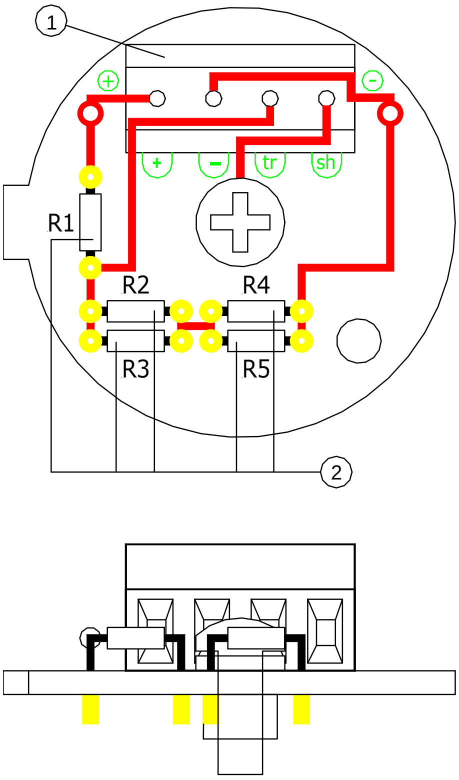

Figure 4.2.2 *Printed circuit board inside SR11; in the normal configuration only +, – and SH are connected to the wiring via the connector block (1). Normally the shunt resistors for trimming (2) are not used.*

4.3 Optional trimming

In case the option "with soldering pins" was ordered, the SR11 sensitivity can be trimmed.

IMPORTANT NOTE: the connection of the wiring on the internal connector block must now be changed.

Sensor	Printed Circuit	Colour code wire
Plus (+)	TR	White
Minus (-)	-	Green
Shield	SH	Wire shield
	+	Not connected

Table 4.3.1 *After trimming: internal connection of SR11 at the connector block.*

Assuming a sensitivity E and no shunt resistors installed, the sensitivity can be changed to E_{new} by installing shunt resistors. This process is called trimming.

1 Measure the SR11 sensor resistance $R_{e\ sen}$. It is suggested to perform this measurement between the + and – of the connector block. The measurement should be performed with dual polarity, taking the average (this is done because some ohmmeters can be confused by the sensor output signal)

The required shunt resistance $R_{e\ sh}$ for trimming to a new value of E, E_{new} , should be chosen according to:

$$R_{e\ sh} = R_{e\ sen} \left(\left(E_{new} / (E_{new} - E \right) \right) \quad 4.3.1$$

For building $R_{e\ sh}$ all the connection points R2 to R5 can be used.
R1 is typically connected with a wire.
In case R4 and R5 are not used, R4 should be shunted with a wire.
After soldering in the wiring can be reconnected using the schedule of 4.3.1.

To establish if the procedure and installation of resistors was correct, the resistance between the + and – wires can be checked:

This should be

$$R_{e\ sen\ new} = 1/((1/ R_{e\ sen})+(1/ R_{e\ sh})) \quad 4.3.2$$

Finally a recalibration should be performed.

4.4 Installation of radiation screens

Radiation screens can be installed and removed using an hex-head wrench (bolt size 2.5mm). See the drawing below. Radiation screens are beneficial for instrument measurement accuracy and instrument and cable lifetime. They also serve as rain- and snow screen. However, also in case radiation screens are not present, the instrument is expected to function within specifications.

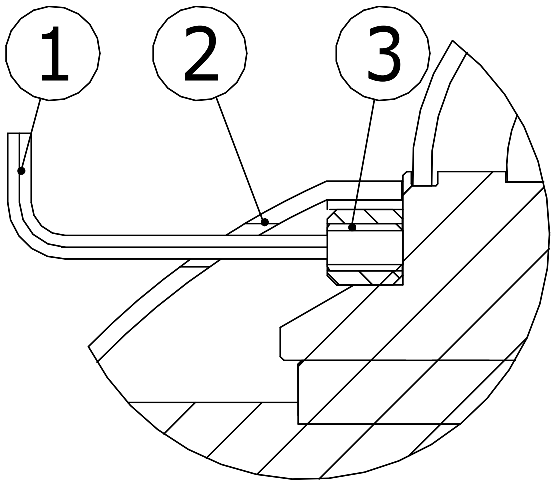

Figure 4.4.1 *installation and removal of radiation screens: (1) hex-head wrench, (2) radiation screen (3) hexagon drive set screw. Size*

5 Dimensions

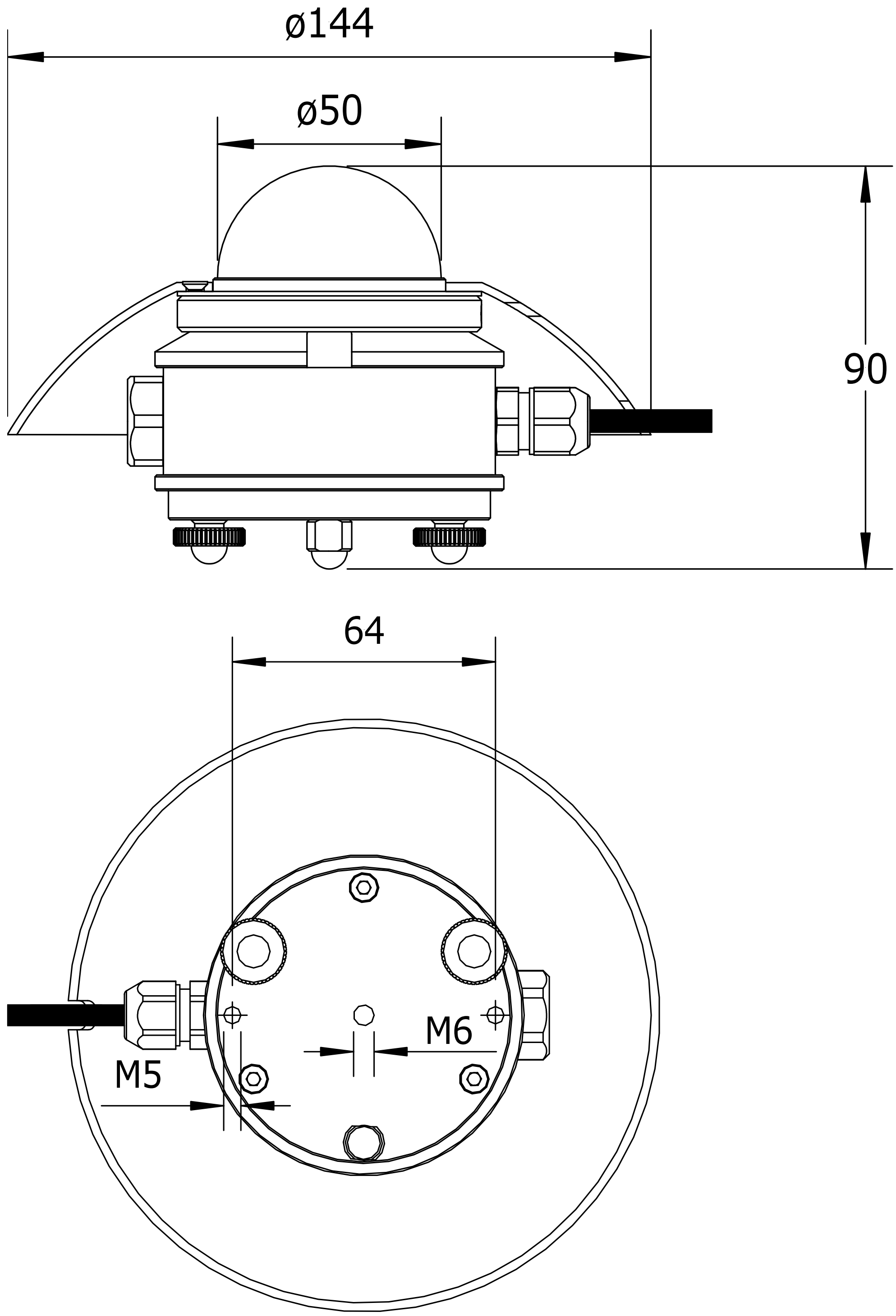

Figure 5.1 *Dimensions of SR11 in mm.*

6 Maintenance and troubleshooting

6.1 Maintenance

Once installed SR11 is essentially maintenance free.
Periodically dessicant may be exchanged.
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.

Critical review of data
Cleaning of dome by water or alcohol
Inspection of dome interior; no condensation
Dessicant inspection : change in case the humidity indicator shows more than 50%, then replace dessicant. Regeneration is possible by heating more than 3 hours. Spanner size required for removal of dessicant is 20. Hexagoanl bolt size for removal of radiation screen is 2.5.
Leveling inspection (remove radiation screen, and change instrument tilt in case this is out of specification)
Inspection of cables for open connections
Recalibration: suggested every 2 years, typically by intercomparison with a higher standard in the field.

Table 6.1.1 *SR11 recommendations for maintenance*

6.2 Trouble shooting

This paragraph contains information that can be used to make a diagnosis whenever the sensor does not function.

The sensor does not give any signal	Measure the impedance across the sensor wires. This should be around 100 ohms plus cable resistance (typically 0.1 ohm/m). If it is closer to zero there is a short circuit (check the wiring). If it is infinite, there is a broken contact (check the wiring). This check can be done even when the sensor is buried. Check if the sensor reacts to an enforced heat flux. In order enforce a flux, it is suggested to use a lamp as a thermal source. A 100 Watt lamp mounted at 10 cm distance should give a definite reaction. Check the data acquisition by applying a mV source to it in the 1 mV range.
The sensor signal is unrealistically high or low.	Check if the right calibration factor is 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 range of the data logger; heat flux can be negative (this could be out of range) or the amplitude could be out of range. Check the data acquisition by applying a mV source to it in the 1 mV range.
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.

Table 6.2.1 *Trouble shooting for SR11.*

6.3 Data quality assurance

Quality assurance can be done by

- analysing trends in solar absolute signal,
- nighttime signals

The main idea is that one should look out for any unrealistic values.

There are programs on the market that atomatically can perfrom data screening; see http://www.dqms.com

7 Requirements for data acquisition / amplification

Capability to measure microvolt signals	Preferably: 5 microvolt accuracy Minimum requirement: 20 microvolt accuracy (both across the entire expected temperature range of the acquisition / amplification equipment)
Capability for the data logger or the software	To store data, and to perform division by the sensitivity to calculate the solar irradiance.

Table 7.1 *Requirements for data acquisition and amplification equipment.*

8 Appendices

8.1 Appendix on cable extension / replacement

SR11 is equipped with one cable. It is a general recommendation to keep the distance between data logger or amplifier and sensor as short as possible. Cables generally act as a source of distortion, by picking up capacitive noise. SR11 cable can however be extended without any problem to 100 meters. If done properly, the sensor signal, although small, will not significantly degrade because the sensor impedance is very low. Cable and connection specifications are summarised below.

NOTE: the body of SR11 contains connector blocks that can be used for internal connection of a new cable. Usually it is easier to connect a new longer cable than to extend an existing cable.

Cable	2-wire shielded, copper core (at Hukseflux 3 wire shielded cable is used, of which only 2 wires are used)
Core resistance	0.1 Ω/m or lower
Outer diameter	(preferred) 5 mm
Outer sheet	(preferred) polyurethane (for good stability in outdoor applications).
Connection	Either solder the new cable core and shield to the original sensor cable, and make a waterproof connection using cable shrink, or use gold plated waterproof connectors.

Table 8.1.1 *Specifications for cable extension of SR11.*

8.2 Appendix on calibration

The World Radiometric Reference (WRR) is the measurement standard representing the SI unit of irradiance. It was introduced in order to ensure world-wide homogeneity of solar radiation measurements and is in use since 1980.
The WRR was determined from the weighted mean of the measurements of a group of 15 absolute cavity radiometers which were fully characterized. It has an estimated accuracy of 0.3%. The WMO introduced its mandatory use in its status in 1979.

The world-wide homogeneity of the meteorological radiation measurements is guaranteed by the World Radiation Centre in Davos Switzerland, by maintaining the World Standard Group (WSG) which materializes the World Radiometric Reference.

http://www.pmodwrc.ch/

The Hukseflux standard is traceable to an outdoor WRR calibration. Some small corrections are made to transfer this calibration to the Hukseflux standard conditions: sun at zenith and 500 W/m^2 irradiance level. (during the outdoor calibration the sun is typically at 20-40 degrees zenith angle, and the total irradiance at a 700 W/m^2 level.

Recalibration of field pyranometers is typically done by comparison in the field to a reference pyranometer. The applicable standard is ISO 9847 "International Standard- Solar Engergy- calibration of field pyranometers by comparison to a reference pyranometer".
At Hukseflux an indoor calibration according to the same standard is used (described in Appendix A of the ISO 9060 standard).

Ther main Hukseflux recommendation for re-calibration is if possible to do it indoor by comparison to an identical reference instrument, under normal incidence conditions.

In case of field comparison; The ISO recommends field calibration to a higher class pyranometer. Hukseflux does not agree with this because in practice this leads to various errors, due to the conditions of the moment. It is therefore just as safe to compare to pyranometers of the same brand and type.

Secondly, the ISO recommends to perform field calibration during several days; 2-3 days under cloudless conditions, 10 days under cloudy conditions. In general this is not achievable.

Hukseflux main recommendations for field intercomparison are:
1 to take a reference of he same brand and type as the field pyranometer, and
2 to connect both to the same electonics, so that electronics errors (also offsets) are eliminated.
3 Preferaboy both instruments should be mounted on the same platform, so that they have the same body temperature.
4 Assuming that the electronics is independently calibrated, it is suggested:
4.1 of possible to look either at radiation values at normal incidence radiation (possibly tilting the radiometers).
4.2 if this is not possible to compare 1 hour or daily totals.
4.3 to take 10 minute average values, and determine the relative calibration by using the correlation between the two signals, assuming the signals to be both zero at zero irradiance.
5 In general for second class radiometers, deviations of more than +/- 10 % should be corrected. Lower deviations should be interpreted as acceptable.
6 For first class pyranometers, the limit could be set at +/- 5%. Lower deviations should be interpreted as acceptable.
7 For secondary standard instuments, provided that they are well cleaned and venilated, the limit could be set at +/- 2%.

8.3 Appendix on sensor coating

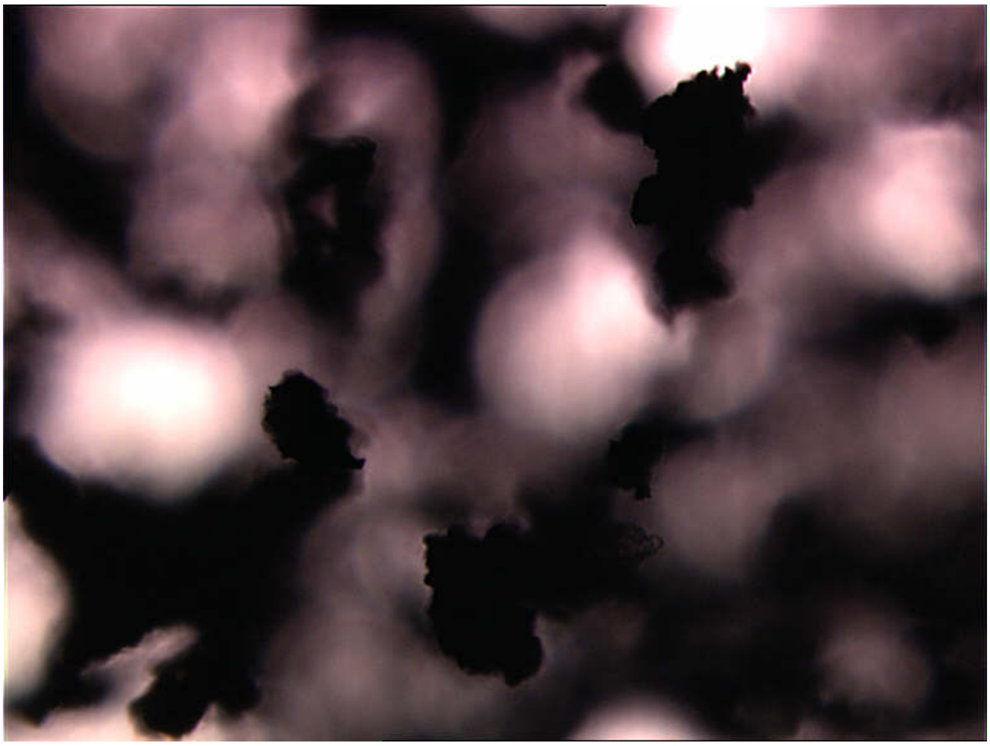

Figure 8.3.1 *Top of the Hukseflux sensor coating on a glass substrate under a confocal laser microscope. The carbon based coating is highly porous, and every element acts as a light trap. The end result is a coating of very high absorption. The ends of carbon particles are in-focus, the outlines of the underlying layers can be seen out-of focus.*

8.4 Declaration of conformity CE

According to EC guidelines 89/336/EEC,

We: Hukseflux Thermal Sensors

Declare that the product: SR11

Is in conformity with the following standards:

Emissions:

Radiated:	EN 55022: 1987	Class A
Conducted:	EN 55022: 1987	Class B

Immunity:

ESD	IEC 801-2; 1984	8kV air discharge
RF	IEC 808-3; 1984	3 V/m, 27-500 MHz
EFT	IEC 801-4; 1988	1 kV mains, 500V other

Delft
May 2007