

Instruction Manual

SGR series • Smart Pyrgeometer

Important User Information

Dear customer, thank you for purchasing a Kipp & Zonen instrument. It is essential that you read this manual completely for a full understanding of the proper and safe installation, use, maintenance and operation of your new SGR series pyrometer.

We understand that no instruction manual is perfect, so should you have any comments regarding this manual we will be pleased to receive them at:

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**KIPP &
ZONEN**
SINCE 1830

Declaration of Conformity



Kipp & Zonen B.V.

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declares under our sole responsibility that the product

SGR3 and SGR4 Smart Pyrgeometer

to which this declaration relates, is in conformity with European Harmonised Standards
as published in the Official Journal of the EU, based on the following standard

[EMC - Emissions] **EN 61326-2-3:2013**

[EMC - Immunity] **EN 61326-2-3:2013**

[Environmental Affairs] **EN 50581:2012**

following the provisions

EMC-directive **2014/30/EU**

RoHS Directive **2011/65/EU**

also, this device complies to

[EMC - FCC] **Title 47CFR part 15**

Delft, 7 February 2017

E. Valks - CEO
Kipp & Zonen B.V.

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1. Introduction

Throughout this manual the following symbols are used to indicate to the user important information.



General warning about conditions, other than those caused by high voltage electricity, which may result in physical injury and/or damage to the equipment or cause the equipment to not operate correctly.

Note Useful information for the user

1.1 Product overview

According to the World Meteorological Organisation (WMO) a pyrgeometer is the designated type of instrument for the measurement long-wave atmospheric radiation.

A SGR series pyrgeometer is a high quality radiometer designed for measuring long-wave irradiance on a plane surface (radiant flux, W/m^2) which results from radiation incident from the hemisphere above the instrument.

This manual, together with the instruction sheet, gives information related to installation, maintenance, calibration, product specifications and applications of the SGR series. Both the SGR3 and SGR4 pyrgeometers are described, even though they have a different construction, the general definitions and principles apply to both models.

The physical construction and detectors are identical to the CGR3 and CGR4. The addition of the Smart interface affects specifications and the number of pins on the connector. Both instruments have a Modbus® RS-485 interface that provides all required information; in addition the analogue output provides the temperature corrected Downward Radiation.

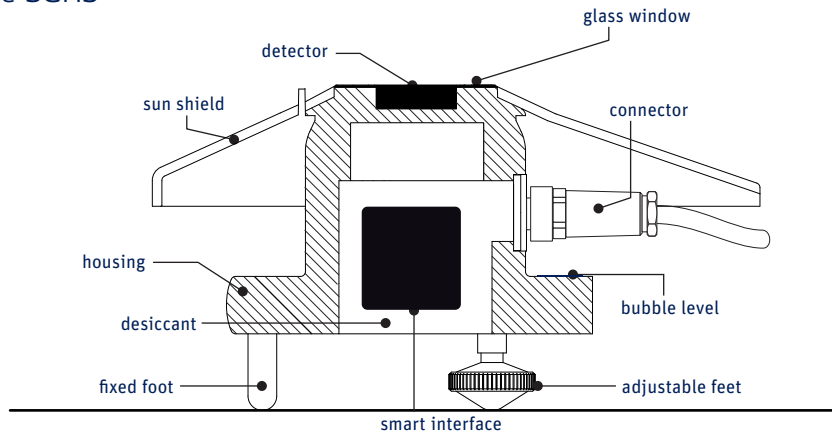
Both the type of radiation and the range for the analogue output can be set by using the Modbus® interface and the free SmartExplorer software.

The Modbus® interfaces for all SGR's, SMP's, SHP1 etc. are fully identical, both for the used registers and the physical connector.

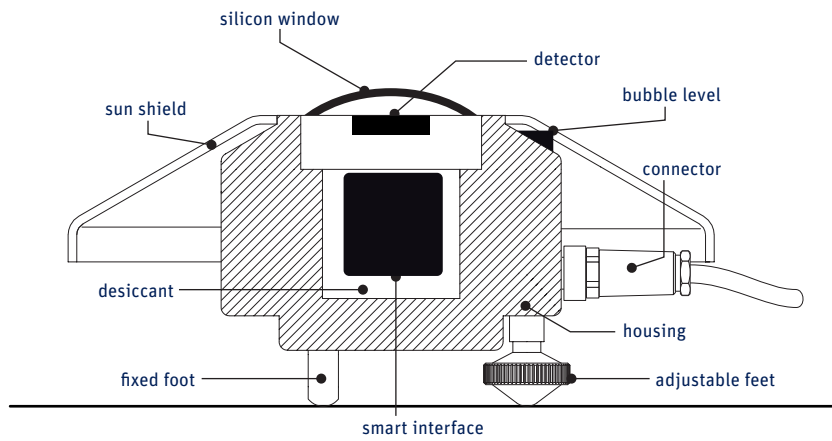
If any questions should remain, please contact your local Kipp & Zonen representative or e-mail the Kipp & Zonen customer and product support department at: support@kippzonen.com

Please go to www.kippzonen.com for information about other Kipp & Zonen products, or to check for any updates to this manual.

1.2 Key parts of the SGR3



1.3 Key parts of the SGR4



2. Installation and operation

Please follow the instructions in this section carefully for the mechanical and electrical installation of the SGR series pyrgeometers.



Do not turn on power to the instrument until instructed to do so.

Note Do not connect the instrument to a computer until instructed to do so.

Note Do not turn on power to the operating computer until instructed to do so.

2.1 Included with the product

Check the contents of the shipment for completeness (see below) and note whether any damage has occurred during transport. If there is damage, a claim should be filed with the carrier immediately. In the case of damage and/or the contents are incomplete, contact your local Kipp & Zonen representative or e-mail the Kipp & Zonen customer and product support department at: support@kippzonen.com

Although all SGR radiometers are weatherproof and suitable for harsh environmental conditions, they have some delicate mechanical parts. Please keep the original packaging for safe transport of the radiometer to the measurement site or for use when returning the radiometer for calibration.

The following items are included with SGR series pyrgeometers:

1. Radiometer
2. Sun shield
3. Optional cable, pre-wired with 8-pins connector or connector only for customer cable
4. Test reports
5. Instruction sheet
6. Radiometer fixing kit

The calibration certificate supplied with the instrument is valid for 1 year from the date of first use by the customer, subject to the variations in performance due to specific operating conditions that are given in the instrument specifications. The calibration certificate is dated relative to the time of manufacture, or recalibration, but the instrument does not undergo any sensitivity changes when kept in the original packing and not exposed to light. From the moment the instrument is taken from its packaging and exposed to irradiance the sensitivity will deviate slightly with time. See the 'non-stability' performance (maximum sensitivity change per year) given in the radiometer specification list.

2.2 Mechanical installation

The mechanical installation of the radiometer depends upon the measuring purpose. Different measuring methods will be explained in the next paragraphs.

2.2.1 Installation for measurement of long-wave downward radiation

The following steps must be carefully taken for optimal performance of the instrument. The tools required to fit an SGR series pyrgeometer to a support are a 4 mm (M5 socket head screw) Allen key and a 8 mm (M5 nut) wrench / spanner.

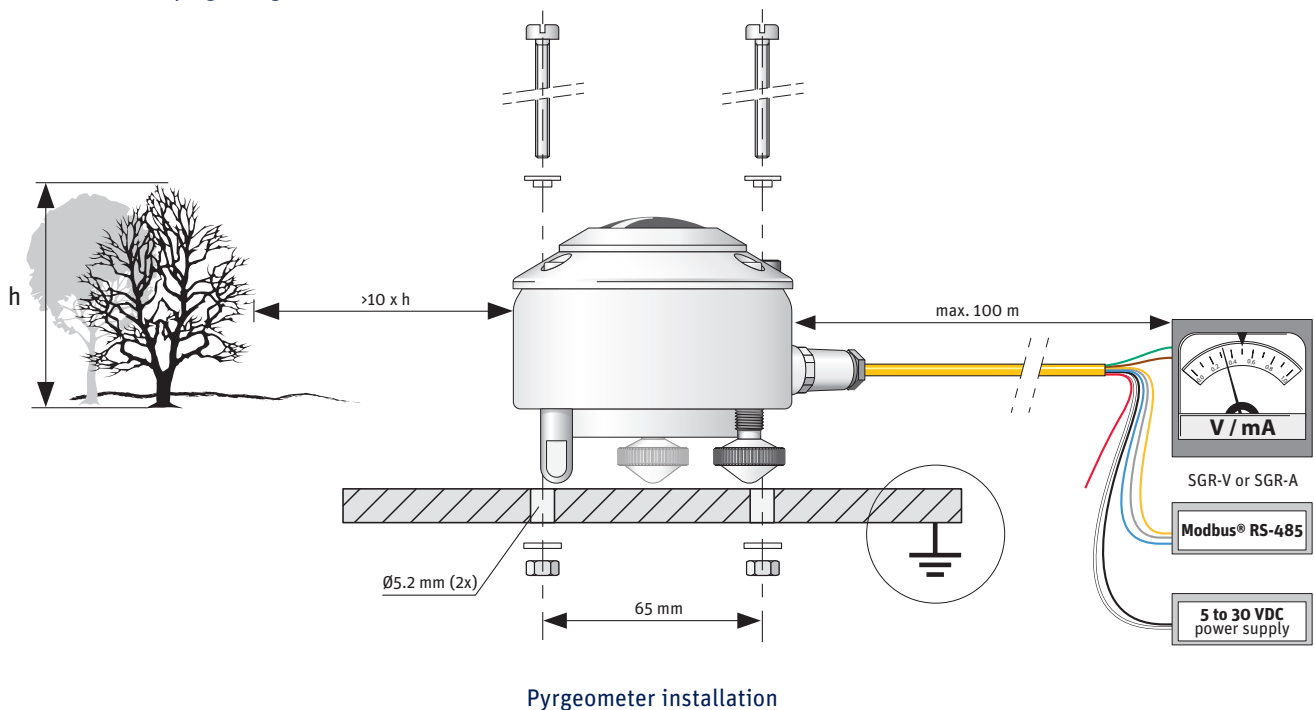
Step 1. Location

Ideally the site for the pyrometer should be free from any obstructions to the horizon above the plane of the sensing element. If this is not possible, the site should be chosen in such a way that any obstruction over the azimuth range should have an elevation not exceeding 10°. In particular, no sources of heat (such as ventilation / heating outlets) should be within the field of view.

Step 2. Mounting

The SGR pyrometer is provided with two holes for 5 mm bolts. Two each of stainless steel bolts, washers, nuts and nylon insulation rings are provided in the fixing kit. The pyrometer should first be secured lightly with the bolts to a solid and stable mounting stand or platform. After in recalibration the nylon insulators must be replaced with new ones to prevent corrosion.

The mounting stand temperature can vary over a wider range than the air temperature. Temperature fluctuations of the pyrometer body can produce offset signals, therefore it is recommended to isolate the pyrometer thermally from the mounting stand by placing it on its levelling screws. Ensure that there is a good electrical contact with earth to conduct away currents in the cable shield induced by lightning.



Note After recalibration and/or reinstallation the nylon insulators must be replaced with new ones to maintain durability.

Step 3. Orientation

In principle no special orientation of the instrument is required, although the World Meteorological Organisation (WMO) recommends that the signal lead is pointed towards the nearest pole, to minimise heating of the electrical connections.

Step 4. Level pyrometer

Accurate measurement of the global radiation requires proper levelling of the thermopile surface. Level the instrument by turning the two levelling screws to bring the bubble of the spirit level centrally within the marked ring. For easy levelling, first use the screw nearest to the spirit level. When the SGR4 pyrometer is placed horizontally using the bubble level, or when it is mounted with its base directly on a horizontal plane, the thermopile is horizontal within 0.1°. For the SGR3 this is 0.2°.

Step 5. Secure pyrheliometer

Secure the pyrheliometer tightly with the two stainless steel bolts. The two nylon washers prevent contact corrosion. Ensure that the pyrheliometer maintains the correct levelled position!

Step 6. Fit cable and sun shield

Locate the cable plug correctly in the radiometer socket (it only fits one way) and screw the plug locking ring hand-tight. Finally, clip on the sun shield to prevent excessive heating of the radiometer body. The bubble level is visible through the top of the pyrheliometer sun shield for routine checks.

2.2.2 Installation for measurement of radiation on inclined surfaces

It is advised to pre-adjust the levelling screws on a horizontal surface for easy orientation of the instrument parallel to the inclined surface. Because the temperature of the mounting stand is expected to rise considerably (more than 10 °C above air temperature), the housing must be thermally isolated by the levelling screws from the stand. This will promote a thermal equilibrium between the window and the housing and decrease zero offset signals.

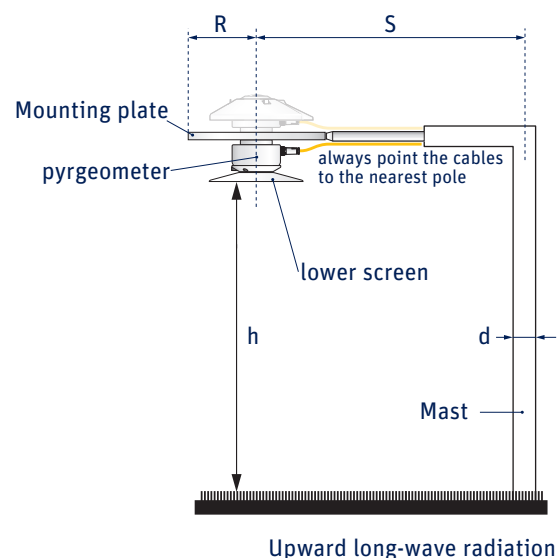
2.2.3 Installation for measurement of upward long-wave radiation

In the inverted position the pyrheliometer measures radiation from the ground. According to the WMO the height should be 1 to 2 m above a uniform surface covered by short grass.

The mounting device should not interfere significantly with the field of view of the instrument. The upper plate prevents excessive heating of the pyrheliometer body by solar radiation and, if large enough, it keeps the lower screen free of precipitation. The lower glare screen prevents direct illumination of the window by the sun at sunrise and sunset and is available as an accessory kit for the SGR series.

The mast shown intercepts a fraction $D/2\pi S$ of the radiation coming from the ground. In the most unfavourable situation (sun at zenith) the pyrheliometer shadow decreases the signal by a factor R^2/H^2 .

A rule of thumb is: A black shadow with radius = 0.1 H on the field below decreases the signal by 1% and 99% of the signal will originate from an area with radius 10 H.



2.2.4 Installation for shaded measurement of downward long-wave radiation

For measuring atmospheric radiation with SGR pyrheliometers it is desirable to shield the instrument from the direct short-wave solar radiation which may heat up the pyrheliometer window and cause significant thermal offsets. The direct solar radiation is intercepted by a small disk or sphere. The shadow of the disk must cover the pyrheliometer window completely. However, to follow the sun's apparent motion, a power-driven tracking device is necessary.

This can be done using a Kipp & Zonen sun tracker, such as the model SOLYS2, designed to track the sun accurately under all weather conditions. More information about the combination of pyrheliometer and tracker is given in the sun tracker manual.

Alternatively, a static shadow ring can be used to intercept the direct solar radiation; but it is less accurate and may require periodic manual adjustment. At times the shadow ring also intercepts a proportion of the diffuse sky radiation. Therefore, corrections for this to the recorded data are necessary.

Kipp & Zonen produces a universal shadow ring, model CM121, which is suitable for use at all latitudes. In the CM121 manual, installation instructions and correction factors are given.

In practice the SGR4 does not require shading from direct short-wave solar radiation because the window-heating effect, when suitably ventilated, is negligible due to the unique construction of the pyrometer.

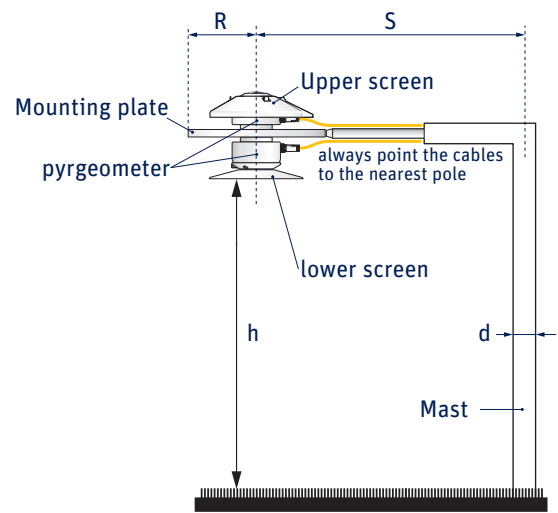
2.2.5 Installation for measurement of net long-wave radiation

A net pyrometer measures both the downward atmospheric long-wave radiation and the upward long-wave radiation from the surface below. It can be configured from two SGR-series pyrometers and a suitable mounting plate. In the case of the SGR3, two instruments can be simply mounted back-to-back and an optional mounting rod fitted.

The requirements for installation of the upper and lower pyrometers are the same as in paragraphs for downward and upward long-wave radiation. According to the WMO the pyrometer configuration should be 1 to 2 meter above a uniform surface covered by short grass.

The mast shown intercepts a fraction $D/2\pi S$ of the radiation that is coming from the ground. In the most unfavourable situation (sun at zenith) the pyrometer shadow decreases the signal by a factor R^2/H^2 .

When determining the net long-wave radiation, it is not strictly necessary to record the pyrometer housing temperatures. Assuming that the temperatures of the upper and lower housings are equal, it can be cancelled from the equation for net-radiation.



Net radiation configuration

However, if the upward and downward radiation components are to be measured separately it is necessary to record the individual housing temperatures to calculate the radiation values.

Using the combination of a net pyrometer (two SGR3 or SGR4 instruments) and an albedometer (two SMP6 or SMP11) the net total radiation (energy balance) can be calculated with high accuracy from the four component values. Problems with dew deposition, frost, etc, can be minimised by using the Kipp & Zonen CVF4 ventilation unit with optional heating.

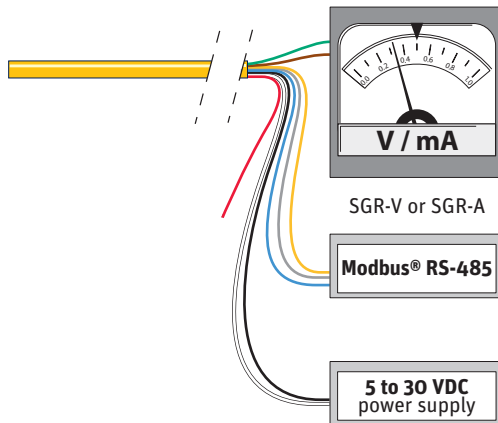
This has many advantages over conventional net total radiation sensors with plastic (polyethylene) windows. These cannot provide individual short and long-wave radiation values and cannot separate upward and downward contributions. The soft plastic windows do not fully protect the sensor from the thermal effects of wind and rain, are easily soiled, are difficult to clean and require regular replacement.

2.3 Electrical connections

The SGR pyrgeometers can be supplied with a waterproof connector pre-wired to 10 m of high quality yellow cable with 8 wires and a shield covered with a black sleeve. Longer cables are available as options. The colour code of the wires and the connector pin numbers are shown below and on the instruction sheet.



Special attention is needed to prevent power or ground loops when connecting the SGR to multiple readout devices. Connecting the RS-485 to a grounded circuit and the analogue output to a floating circuit can cause unacceptable ground loops. This may cause differential voltages outside the SGR specifications and will damage the unit. We recommend using either the analogue or the digital output but not both. The maximum differential between either of the Modbus® RS-485 lines (yellow and grey) and the power ground / RS-485 common line (black) is 70 VDC.



Radiometer Connection		
Wire	Function	Connect with
3	Green	Analogue out
6	Brown	Analogue ground
4	Yellow	Modbus® RS-485 B/B'+
5	Grey	Modbus® RS-485 A/A'-
7	White	Power 5 to 30 VDC (12 V recommended)
8	Black	Power ground / RS-485 Common
1	Red	None
2	Blue	Modbus® common / Ground
	Shield	Housing
		Ground *

* Connect to ground if radiometer not grounded



First connect all wires before plugging into the radiometer



The shield of the cable is connected to the aluminium radiometer housing through the connector body. Preferably, secure the radiometer with its levelling screws on a metal support with a good connection to ground (e.g. by using a lightning conductor) and do not connect the cable shield at the readout end.



If there is no good ground connection at the pyrgeometer, the shield at the cable end should be connected to ground at the readout equipment. Lightning can induce high voltages in the shield but these will be led off at the pyrgeometer or readout equipment.

Note

Long cables may be used, but the cable resistance must be smaller than 0.1% of the impedance of the readout equipment for the analogue outputs and may affect the baud rate of the RS-485 digital connection.

2.3.1 Power connection

The minimum power supply voltage for SGR pyrgeometers is 5 VDC. However, for optimal performance it is advised to use 12 VDC, especially when long cables are used. 5-volt power can only be used in combination with a short cable, maximum 10 m.

It is advised to protect the output of the power supply with a fast blowing fuse of maximum 250 mA rating.

Typical power consumption SGR-V for maximum output (1 V)		
5 VDC	50 mW	(approx. 10.0 mA)
12 VDC	55 mW	(approx. 4.5 mA)
24 VDC	60 mW	(approx. 2.5 mA)

Maximum power consumption 65 mW at the highest input voltage.

Maximum input current 12.5 mA at the lowest input voltage.

Maximum inrush current 200 mA.

Typical power consumption SGR-A for max output (20 mA)		
5 VDC	77 mW	(approx. 28 mA with 100 Ω load resistor)
12 VDC	83 mW	(approx. 24 mA with 100 Ω load resistor)
24 VDC	100 mW	(approx. 6 mA with 100 Ω load resistor)

The above mW values represent the dissipation within the SGR-A. For the total power the energy in the load resistor has to be added.

For supply voltages below 12 Volts or above 20 Volts it is advised to use a load resistor of less than 500 Ω to keep the power consumption as low as possible.

2.3.2 Data connection

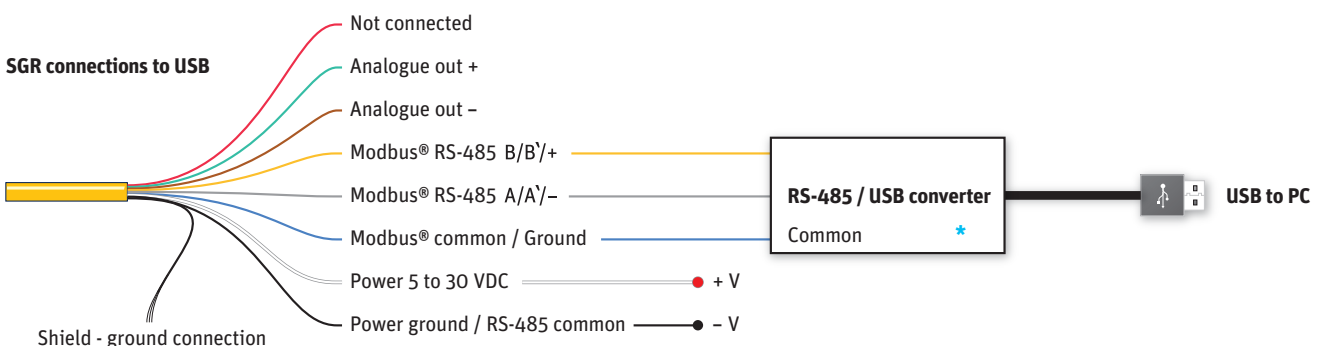
Connection to a Personal Computer by Universal Serial Bus (USB)

The connection depends on the use of a RS-485 to USB converter.



The converter **must** have galvanic isolation between the inputs and outputs to prevent possible damage to the SGR digital interface. This is particularly an issue with portable computers (laptops, etc.) in which the power supplies can generate large voltage spikes.

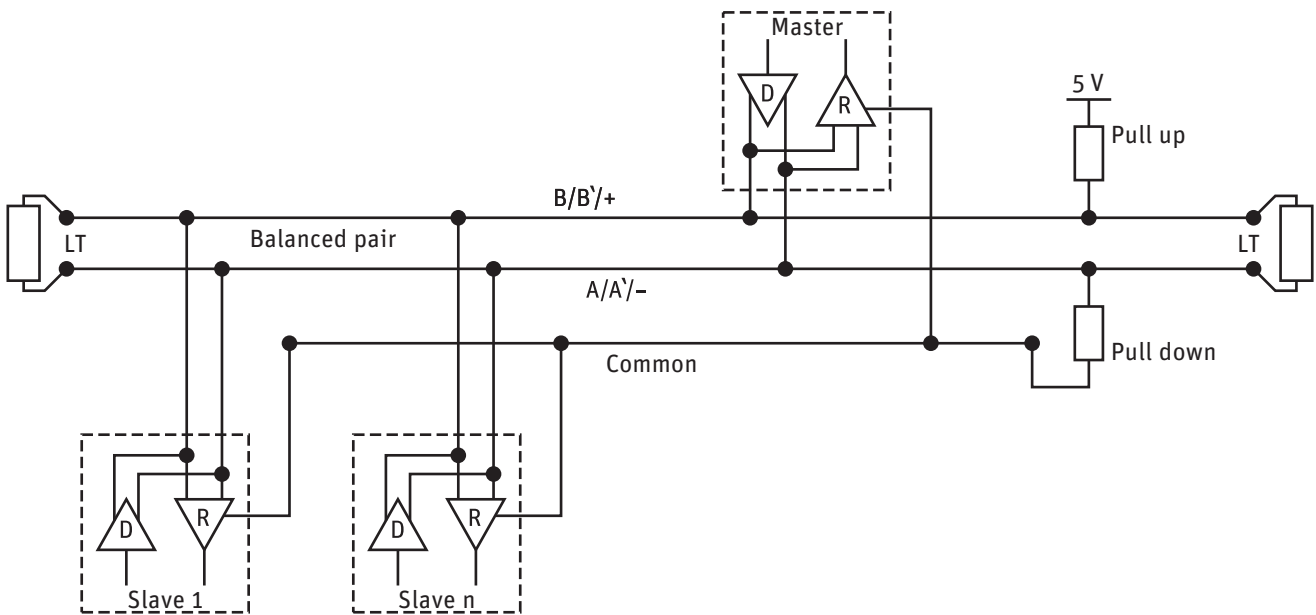
A suitable converter is the model USOPTL4 from B & B Electronics. One end has the USB connector to the PC the other end has a connector with screw terminals for the instrument wires. This RS-485 converter is powered from the USB interface, so no additional power adaptor is necessary.



***Note** Switches on the converter should be set for RS-485, 2-wire operation and Echo off.

Connection to a RS-485 Network

The digital interface can be connected to a 2-wire RS-485 network as shown below.



The slaves and master may be a SGR pyrgeometer or other devices. If a SGR pyrgeometer is the last device on the network a line terminator (LT), consisting of a 120 Ω or 150 Ω resistor, must be connected between terminals A/A'- and B/B'+. Never place this line termination on the derivation cable. It is also required to install the pull up and pull down resistors as shown. The value of these resistors must be between 650 Ω and 850 Ω.

2.3.3 Analogue voltage output

The SGR-V (voltage output versions) have been factory set such that an output of 0 Volts represents 0 W/m² (this will never be reached in practice), and the full-scale output of 1 Volt represents 1000 W/m².

The voltage output range in W/m² can be changed by the user with the supplied PC software. The maximum recommended irradiance for all SGR pyrgeometers is 1000 W/m².

The default setting 0 to 1 Volt represents 0 to 1000 W/m².

The downward atmospheric long-wave radiation ($L_{d\downarrow}$) for the default setting can be simply calculated as shown below.

$$L_{d\downarrow} = (V \times 1000)$$

$L_{d\downarrow}$ = Downward atmospheric long-wave radiation [W/m²]

V = Output of radiometer [Volt]

If the pyrgeometer is used in atmospheric conditions it is advised to keep the range as factory default.

2.3.4 Analogue current output

The SGR-A (current output versions) have been factory set such that an output of 4 mA represents 0 W/m² and the full-scale output of 20 mA represents 1000 W/m².

The current output range in W/m² can be changed by the user with the supplied PC software. The maximum recommended irradiance for the SGR pyrgeometers is 1000 W/m².

Negative inputs will make the output go below 4 mA and no zero offset is needed. For the default setting of 4 to 20 mA representing 0 to 1000 W/m². The irradiance value ($L_{d\downarrow}$) for the default setting can be simply calculated as shown below.

$$L_{d\downarrow} = (\text{mA}-4) \times (1000/16)$$

$L_{d\downarrow}$ = Downward atmospheric long-wave radiation [W/m²]

mA = Output of radiometer [mA]

2.3.5 Recommended cable types

Where cables need to be extended, or the customer prefers to provide their own cables, they should be suitable for outdoor use and UV resistant.

Recommended types	
RS-485	Ethernet CAT 5 shielded twisted pair (STP)
0 to 1 V	Shielded 2-core signal cable
4 to 20 mA	Shielded twisted pair control cable

2.4 Operation

After completing the installation the pyrgeometer will be ready for operation. The downward atmospheric long-wave radiation is calculated automatically inside the pyrgeometers with formula L_d by measuring the detector output voltage U_{emf} [μ V], the housing temperature T_b [K], and taking the sensitivity calibration factor S [μ V/W/m²] into account.

$$L_d = \frac{U_{emf}}{S} + 5.67 \cdot 10^{-8} \cdot T_b^4 \quad \text{formula } L_d$$

L_d = Downward atmospheric long-wave radiation [W/m²]

$\frac{U_{emf}}{S}$ = Net radiation (difference between the downward longwave radiation emitted from the atmosphere and the upward irradiance of the SGR detector) [W/m²]

$5.67 \cdot 10^{-8} \cdot T_b^4$ = Upward irradiance of the SGR detector [W/m²]

Note The net radiation term (U_{emf}/S) is mostly negative, so the calculated downward atmospheric long-wave radiation is smaller than the detector's upward irradiance ($5.67 \cdot 10^{-8} \cdot T_b^4$).

In the Baseline Surface Radiation Network (BSRN) manual (WMO/TD-No.897) an extended formula is described. This formula corrects for window heating and so called 'solar radiation leakage'. Due to the very low window heating offset and optimal spectral cut-on wavelength, these corrections are not necessary for the pyrgeometer.

To be certain that the quality of the data is of a high standard, care must be taken with daily maintenance of the pyrgeometer. Once a voltage measurement is taken, nothing can be done to retrospectively improve the quality of that measurement.

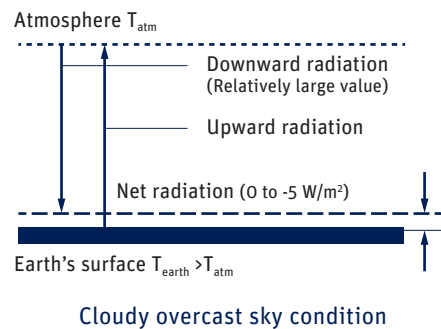
During field measurements the pyrgeometer is exposed to varying atmospheric conditions with typical radiating properties. Therefore we define the two most common conditions as 'overcast sky' and 'clear sky'.

2.4.1 Overcast sky

Typical for a cloudy overcast sky is that radiation emitted by the earth is absorbed 100% by the clouds. Therefore, the overcast sky will re-emit the radiation (L_{\downarrow}) 100%.

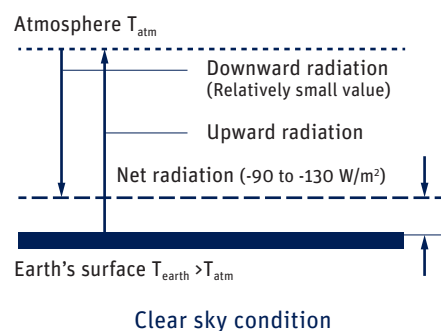
In theory, the net radiation (U_{emf}/S) will be zero, so the pyrgeometer detector output voltage (U_{emf}) will be zero. In practice, the detector output shows a small negative voltage (a few W/m^2), due to a small heat exchange between the relatively warm pyrgeometer and the colder sky.

In this case the calculated atmospheric long-wave radiation (L_{\downarrow}) shows a relatively large positive value. In the case of rain, the detector output will read zero, because water deposited on the pyrgeometer window is a perfect infrared absorber.



2.4.2 Clear sky

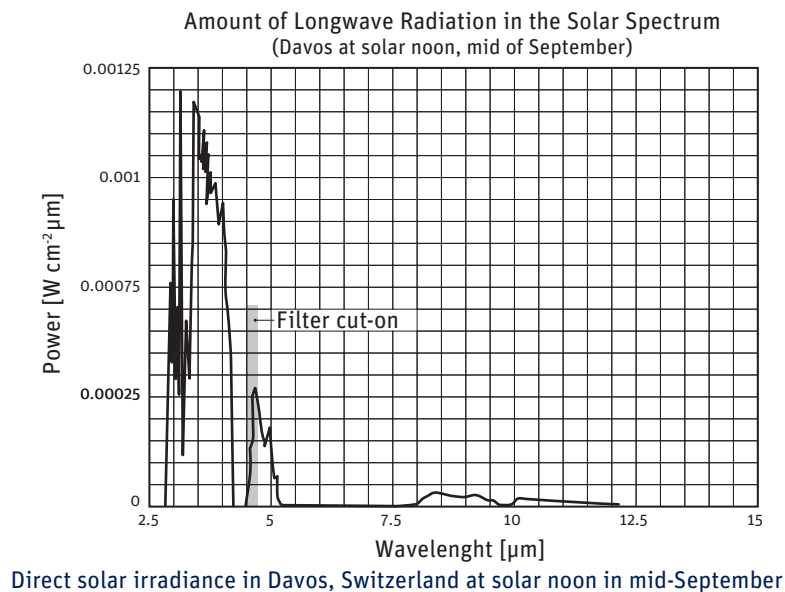
Clear sky conditions differ in that there is a relatively large heat loss caused by the atmospheric window. The amount of re-emitted radiation by a clear sky is smaller compared to the overcast sky condition. Because of the heat loss in the upward direction, the thermopile hot junctions will cool down and show a relatively large negative net radiation value (from -90 to -130 W/m^2). Therefore, the calculated atmospheric long-wave radiation (L_{\downarrow}) shows a relative small positive value.



2.4.3 Measurements during a sunny day

The SGR4 differs from all other pyrgeometers in that it allows accurate daytime measurements on sunny days without the need for a shading device. Due to the unique construction of the SGR4, solar radiation of up to 1000 W/m² induces window heating of less than 4 W/m² in the overall calculated downward radiation.

Formula 1 can be applied without any problems with the following exception; one must take note of the amount of infrared radiation in the solar spectrum. The amount of solar infrared radiation depends on many parameters; for example the water vapour content in the atmosphere (humidity), location of the SGR4 at a certain altitude and the sun's declination angle. The next graph indicates the possible infrared radiation in the solar spectrum in the case of low water content in the atmosphere. The amount of solar infrared detected at the SGR4 (and the SGR3) is expected to be very low (0 to 3 W/m²) because of the filter cut-on at 4.5 μm. Other types of pyrgeometers can exhibit 0 to 10 W/m².

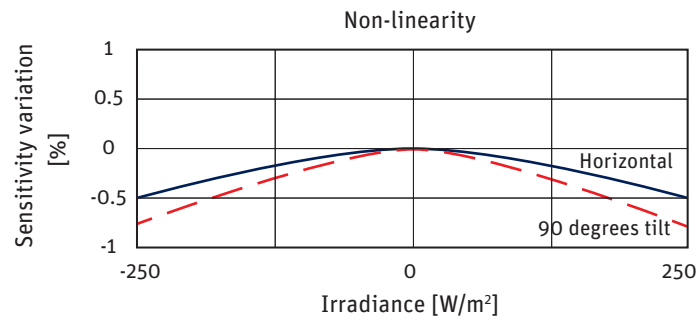


2.5 Measurement uncertainty

When a pyrgeometer is in operation, the performance of it is correlated to a number of parameters, such as temperature, level of irradiance, angle of incidence, etc. Normally, the supplied sensitivity figure is used to calculate the irradiances. If the conditions differ significantly from calibration conditions, uncertainty in the calculated irradiances must be expected.

Kipp & Zonen expects maximum uncertainty below 3% for daily totals for the SGR4 pyrgeometer. This remaining uncertainty can be reduced further if the sensitivity of the pyrgeometer under the prevailing conditions is used, with corrections calculated from the effects of parameters such as temperature and non-linearity. This is especially convenient with a programmable data acquisition system.

For the SGR4 the effect of each parameter on the sensitivity can be shown separately. The non-linearity error, the sensitivity variation with irradiance, is the same for any SGR4.



Non-linear sensitivity variation with irradiance of a SGR4 pyrgometer

2.6 Maintenance

Once installed the pyrgometer needs little maintenance. The window must be cleaned and inspected regularly, ideally every morning. On clear windless nights the window temperature of horizontally placed pyrgometers will decrease, even to the dew point temperature of the air, due to infrared radiation exchange with the cold sky. (The effective sky temperature can be 30°C lower than the ground temperature). In this case dew, glazed frost or hoar frost can be precipitated on the top of the window and can stay there for several hours in the morning. An ice cap on the window is a strong diffuser and increases the pyrgometer signal drastically, up to 100% in the first hours after sunrise. Hoar frost disappears due to solar radiation during the morning, but should be wiped of as soon as possible manually.

The window of the pyrgometer can be ventilated continuously by a heated blower to keep the window above the dew point temperature. The need for heating strongly depends upon local climatological circumstances. Generally, heating is advised during cold seasons when frost and dew can be expected. The Kipp & Zonen CVF4 ventilation unit is specially designed for unattended operation under most weather conditions and has a choice of heating levels.

Note The SGR3 pyrgometer can be used with the CVF4 ventilation unit but is less effective.

A periodic check is to ensure that the pyrgometer is level. The pyrgometer sensitivity changes with time and with exposure to radiation. Calibration every two years is advised.

To keep the detector and electronics dry and to prevent condensation forming inside the windows with temperature changes an internal desiccant is used to absorb humidity within the pyrgometer and lasts for 10 year. The desiccant will be exchanged when these instruments comes back to a Kipp & Zonen service location for recalibration.

3. Accessories

Below is a brief description of the accessories available for SGR series pyrgeometers. Detailed information can be found on our website, where the brochures and manuals for these accessories can be viewed and downloaded.

3.1 Diffuse radiation measurement

For measuring diffuse radiation a shading device is required. Kipp & Zonen can offer several options for SGR pyrgeometers:

Shadow ring CM121B for a SGR3 or an unventilated SGR4

Shadow ring CM121C for a ventilated SGR4

This shadow ring needs to be adjusted manually every 3-5 days and corrections made for the sky obscuration by the ring.

An automated and more accurate way to measure diffuse radiation is to use an automatic sun tracker fitted with a shading mechanism:

SOLYS2 sun tracker + shading ball assembly

SOLYS Gear Drive sun tracker + shading ball assembly

3.2 Ventilation

To further improve measurement accuracy of the SGR4 pyrgeometers the CVF4 ventilation unit can be used. CVF4 has a tachometer output to monitor the fan speed and 5 or 10 Watt heater. The advantages of a CVF4 are:

Lower thermal offsets

No precipitation or condensation on the window

Less dirt on the window

Frost, snow or ice can be melted

Less frequent cleaning required

3.3 Mountings

For mounting pyrgeometers the following plates and brackets are available:

Mounting rod for SGR3

CMF1 mounting fixture with rod for mounting one or two unventilated SGR4's

CMF4 mounting plate with rod for mounting one or two ventilated SGR4's

CMB1 mounting bracket to fix and adjust a mounting rod to a mast, pole or wall

Adjustable tilt mounting kit allows tilting of a SGR pyrgeometer, It has a clear scale for setting the desired angle.

3.4 Cables

Different cable lengths with pre-wired waterproof connector plug, or a connector only can be supplied.

10 m cable with connector

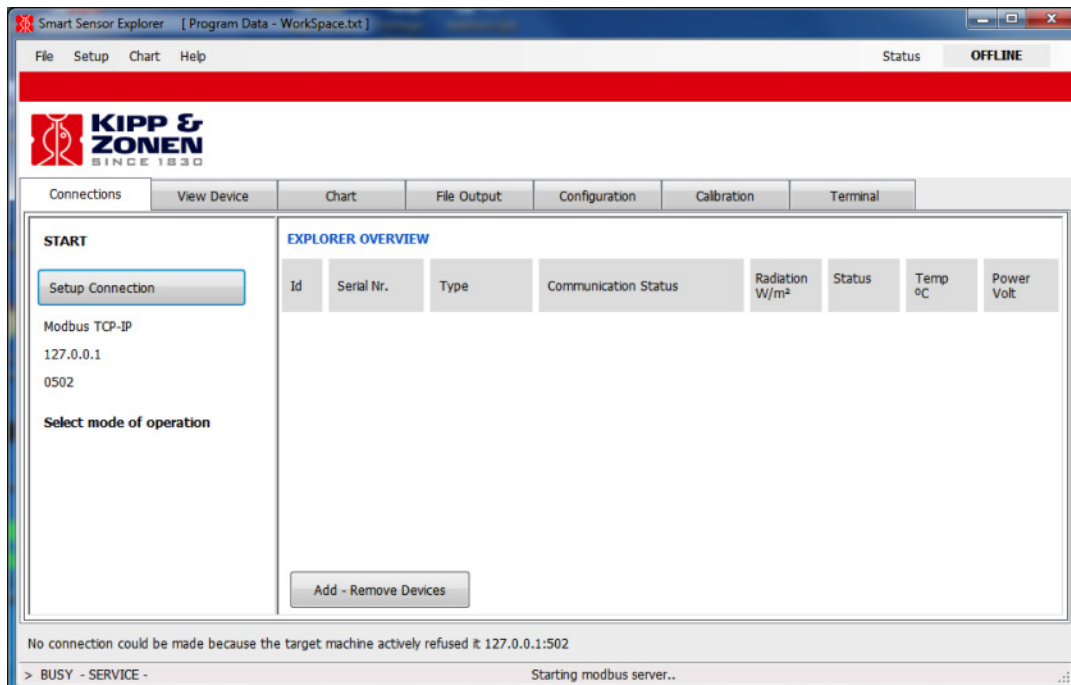
25 m cable with connector

50 m cable with connector

Connector only, no cable

4. SmartExplorer software and Modbus® communication

The SmartExplorer software allows you to configure a smart sensor and to collect real-time data. SmartExplorer runs on a PC with Windows Vista, 7 or 8 and when installing downloads the .NET 4.5 frame work from the Microsoft Server. When using the software on site, make sure the software is already installed on your laptop.



To connect a smart radiometer to a PC, a RS-485 to USB converter is required. Recommended is using an isolated version like the 'USOPTL4' from B&B for safety and protection of the PC.

- Configuration makes it possible to configure a smart sensor 'out of the box' and test the smart sensor before the sensor is used in an operational network.
- The SmartExplorer software can use a RS-485 to USB or Ethernet interface to connect to a PC
- Collecting data makes it possible to store data from the smart sensor in a comma separated file. The comma separated file is created at the beginning of every new day or at the beginning of the first day of the week.
- The SmartExplorer software can also be used to monitor and/or log up to 10 instruments simultaneously and works with all smart radiometers (SMP, SHP, SGR, SUV)

Please check the separate SmartExplorer manual for detailed information about the set-up, monitoring and data logging of the smart sensors. The latest version of the manual can be downloaded the from the relevant product page under the tab 'Download' from our website.

The factory default communication parameters for all Smarts are:

- The factory default Baud rate of a smart sensor is '19200 baud'
- The factory default Size and Parity is '8 bits - even - 1 stopbit'
- The factory default Modbus® address is 1

5. Principle components of pyrgeometers

The detector of the Kipp & Zonen SGR series pyrgeometer is based on a passive thermal sensing element called a thermopile. Although the detector construction differs from model to model, the fundamental working principle is applicable to all SGR series radiometers.

The thermopile responds to the total power absorbed by the black surface coating, which is a nonspectrally selective paint, and warm up. The heat generated flows through a thermal resistance to the heat-sink (the pyrgeometer body). The temperature difference across the thermal resistance of the detector is converted into a voltage as a linear function of the absorbed long-wave irradiance.

The rise of temperature is easily affected by wind, rain and thermal radiation losses to the environment ('cold' sky). Therefore the detector is shielded by a silicon meniscus window (the entry-level SGR3 has a flat silicon window). To keep the detector and electronics dry and to prevent condensation forming inside the windows with temperature changes an internal desiccant is used to absorb humidity within the pyrgeometer.

5.1 Window

The inner surface of the silicon window has an interference filter deposited on it for transmitting the long-wave radiation and blocking the short-wave solar radiation from reaching the detector. The silicon window material and the deposited 'solar blind' filter defines the spectral measurement range of the pyrgeometer.

The silicon window allows transmittance of the atmospheric long-wave radiation up to approximately 42 μm and about 50 to 60% of the radiation spectrum will be transmitted through to the detector. The outer surface of the window has a hard-carbon, diamond-like layer, deposited as additional protection against environmental influences in harsh environments and to smooth out the window transmission beyond 30 μm .

The solar blind filter is opaque to radiation below 4.5 μm , known as the cut-on wavelength. Currently most pyrgeometers have their cut-on at a lower wavelength. Problems may occur in the case of clear sunny days with low humidity. In the solar spectrum between 2.5 and 4.5 μm there can still be an amount of infrared solar radiation up to 10 W/m^2 , which should not be included in the measurement. This unwanted fraction is blocked in the SGR4 by the filter coating.

SGR4 uses a specially designed pure silicon window. Although the window is not hemispherical, SGR4 has a 180° field of view with good cosine response. A big advantage of the meniscus shaped window over the typical hemispherical window is the ability to deposit more uniform coatings on the window surface. Deposition of a uniform filter coating on a strongly curved surface is very difficult and unpredictable process. To avoid these problems Kipp & Zonen developed a window with excellent optical quality due to the optimised shape and coating uniformity.

The solar radiation absorbed by the window is conducted away very effectively by a unique construction in the SGR4. Even in full sunlight the window heating effect is very low compared to that of other pyrgeometers on the market. This allows accurate daytime measurements without the need for a shading disk. It also eliminates the need for window heating compensation by using the correction formula and window temperature sensors.

5.2 Detector

The thermopile sensing element is made up of a large number of thermocouple junction pairs connected electrically in series. The absorption of thermal radiation by one of the thermocouple junctions, called the active (or 'hot') junction, increases its temperature. The differential temperature between the active junction and a reference ('cold') junction kept at a fixed temperature produces an electromotive force directly proportional to the differential temperature created. This is a thermoelectric effect. The sensitivity of a pyrgeometer depends on the individual physical properties of the thermopile and construction. The sensitivity of each thermopile is unique and therefore each radiometer has unique calibration factor, even with the same radiometer model.

On the top surface of the sensor a black paint is deposited which has a very rough structure containing many micro-cavities that effectively 'trap' more than 95% of the incident radiation in a broad spectral range. Furthermore, the spectral selectivity is less than 3%. This means that within the spectral range of the pyrgeometer, the absorption for each wavelength is equal to within 3%. The black painted sensing element forms the detector. Considering the long-term stability of the instrument, the black paint is one of the most crucial and delicate parts of the pyrgeometer. Kipp & Zonen black paint gives the best possible stability over a long period of time under all meteorological circumstances.

5.3 Temperature sensor

The housing temperature sensor is a crucial part of a pyrgeometer and is needed to calculate the downward long-wave radiation component. The body temperature sensor represents the 'absolute' temperature of the detector surface and therefore it is mounted close to the cold junctions of the detector. A housing temperature sensor is fitted as standard to the SGR pyrgeometers.

5.4 Housing

The radiometer housing accommodates all fundamental pyrgeometer parts. The anodized Aluminium parts are light weight and give a high mechanical and thermal stability to the instrument. Due to its fine mechanical construction all pyrgeometers are virtually sealed and comply to the international standard IP 67. Each pyrgeometer model can be leveled by using the bubble level and two leveling feet. For ease of maintenance the bubble level is situated next to the window of the instrument and due to the special shape of the sun shield it is visible from above. The sun shield acts to protect all the external parts from radiation and to reduce solar heating of the housing.

5.5 Cable and connector

For ease of installation and replacement during recalibration of the radiometer, the SGR series are provided with a weather proof signal cable connector.

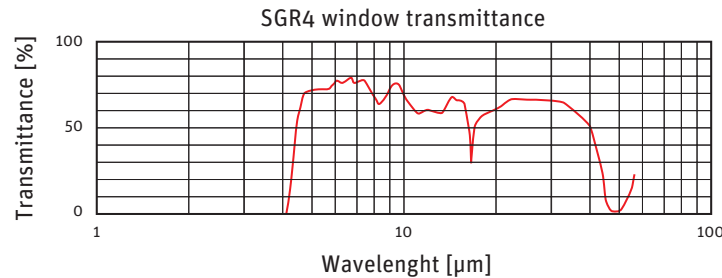
Kipp & Zonen radiometers use a custom-made cable that is selected with a high UV resistance and low electrical resistance.

The shield of the cable is connected to the metal body of the connector and preferably should be connected to ground at the readout equipment. Cables come pre-wired to the connector plug in a range of lengths.

6. Pyrgeometer physical properties

6.1 Spectral range

The spectral properties of the pyrgeometer are mainly determined by the filter characteristics of the silicon window and the coatings. The application is primarily to measure long-wave downward atmospheric radiation. The spectral range is from 4.5 to 42 μm , where most of this radiation is present.



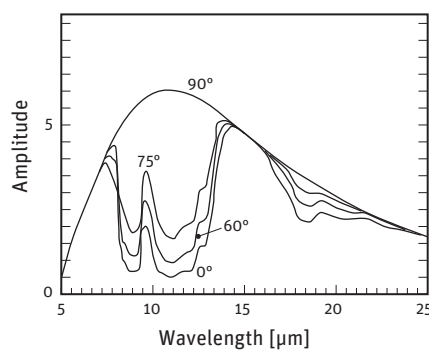
Pyrgeometer spectral window properties

The atmosphere is transparent to long-wave radiation emitted by the Earth's surface in certain wavelength intervals, particularly within a spectral range of approximately 8 to 14 μm . This is called the 'atmospheric window'. Within this spectral range the Earth is able to maintain an equilibrium temperature by losing a certain quantity of heat gained each day from the sun.

The sun radiates approximately as a blackbody at an equivalent temperature of 5770K. Almost 99% of its emitted energy is contained in wavelengths less than 4 μm , called short-wave radiation. The equivalent radiant temperature of the Earth's surface is about 275K. More than 99% of this energy is emitted at wavelengths greater than 3 μm and is called long-wave, thermal, or infrared radiation.

Downward long-wave radiation is a result of atmospheric re-emission. Re-emission is the reversible effect of absorption of long-wave radiation emitted by the Earth and by chemical elements such as water (H_2O), Oxygen (O_2), Ozone (O_3), Carbon dioxide (CO_2), etc. These elements are the main emitters of long-wave radiation in the atmosphere. The remaining unabsorbed portion of the Earth's radiation escapes into outer space. Under clear skies an object can be cooled below ambient air temperature by radiative heat loss to the sky.

Observing the earth from outer space, a blackbody is seen in a range of 8 to 14 μm with a temperature of 14°C and outside this wavelength range a blackbody of -60°C. Under clear sky conditions in a reverse direction, outer space can be observed in the same spectral range.



Atmospheric radiation

6.2 Sensitivity

The radiometer thermopile sensitivity is mainly determined by the physical properties of the detector itself. The thermoelectric power, thermal conductivity of the junctions and the overall dimensions of the sensing element are related to its sensitivity.

6.3 Response time

Any measuring device requires a certain time to react to a change in the parameter being measured. The radiometer requires time to respond to change in the incident radiation. The response time is normally quoted as the time for the output to reach 95% (sometimes 63%) of the final value following a step-change in irradiance. It is determined by the physical properties of the thermopile and the radiometer construction. SGR series pyrgeometers have a fast response, which makes them suitable for measuring far infrared radiation (FIR) under variable weather conditions.

6.4 Non-linearity

The non-linearity of a pyrgeometer is the percentage deviation in the sensitivity over a net irradiance range from -250 to +250 W/m² compared to the sensitivity calibration irradiance of -100 W/m². The non-linearity effect is due to convective and radiative heat losses at the black absorber surface which make the conditional thermal equilibrium of the radiometer non-linear.

6.5 Temperature dependence

The sensitivity change of the pyrgeometer with ambient temperature is related to the thermodynamics of the radiometer construction. For the SGR3 this dependency is measured for a large series of instruments and the average dependency is corrected by the Smart Interface. This gives the SGR3 a better temperature performance than the CGR3.

For every SGR4 the temperature dependency is individually measured and corrected. This correction is over a range of -40 to +70°C. The corrected value is available via the analogue and digital outputs.

6.6 Tilt error

This is the deviation from the sensitivity at 0° tilt (exactly horizontal) over the range from 0° to 90° tilt. The tilt response is proportional to the incident radiation. The error could be corrected for, in applications where it is necessary to install the pyrgeometer on an inclined surface, but is usually insignificant.

6.7 Window heating offset

Currently the major source of error concerning common pyrgeometer measurements is caused by the so-called 'window heating offset'. When a pyrgeometer is exposed to the sun, heating of the silicon window occurs due to absorption of solar radiation by the material. As a consequence the window of most types of pyrgeometer will heat up proportionally to the solar irradiance.

The resulting temperature difference between window and thermopile will cause heat transfer by radiation and convection to the sensor. This affects the net thermal radiation as measured by the thermopile and is commonly referred to as the 'window heating offset'. The result is measurement of a too high value for downward long-wave radiation.

This offset is not easily reduced by ventilation, which only cools off 50 W/m²/°C at maximum while solar radiation can be absorbed at a rate of about 500 W/m² on a sunny day. Currently certain types of pyrgeometers are equipped with one or more thermistors to measure the window absolute temperature that represents the apparent offset. A complex calculation must be performed to eliminate the offset.

The SGR4 has a unique designed construction that minimizes the window heating by conducting the heat into the housing. Temperature variations between window and detector are less than 0.3°C, compared with up to 3°C for other types of pyrgeometers. In SGR 4 the window heating offset is less than 4 W/m². This allows accurate daytime measurements, even in full sunlight, without the need for a tracking shading disk.

6.8 Zero offset B due to ambient temperature changes

Proportionally to the ambient temperature the instrument temperature varies and causes heat currents inside the instrument. This will cause an offset commonly called Zero Offset type B. It is quantified as the response in W/m^2 to a 5 K/hr change in ambient temperature.

6.9 Operating temperature

The operating temperature range of the radiometer is determined by the physical properties of the individual parts. Within the specified temperature range Kipp & Zonen radiometers can be operated safely. Outside this temperature range special precautions should be taken to prevent any physical damage or performance loss of the radiometer. Please contact your distributor for further information regarding operation in unusually harsh temperature conditions.

6.10 Field of view

The field of view is defined as the unobstructed open viewing angle of the radiometer. WMO requires that a high quality pyrgeometer for the measurement of long-wave atmospheric radiation has a field of view of 180° in all directions (i.e. a hemisphere). SGR4 achieves this. The inherent field of view of the instrument should not be confused with the clear field of view of the installation location. For less critical applications pyrgeometers having a flat silicon window with a typical field of view of 150° are acceptable, such as the SGR3.

6.11 Directional response

Radiation incident on a flat horizontal surface originating from a point source with a defined zenith position will have an intensity value proportional to the cosine of the zenith angle of incidence. This is sometimes called the 'cosine-law' or 'cosine-response' and is very important in the measurement of short-wave solar radiation. However, the directional response of pyrgeometers is largely irrelevant since the hemisphere above does not act like a point source.

6.12 Maximum irradiance

The maximum irradiance is defined as the total irradiance level beyond which physical damage may occur to the instrument.

6.13 Non-stability

This is the percentage change in sensitivity over a period of one year. This effect is mostly due to degradation by UV radiation of the black absorber paint on the sensing element surface. Kipp & Zonen recommends recalibration every two years. However, for quality assurance purposes some institutes, companies or networks may require more or less frequent recalibration. Please read the chapter on the calibration procedure for pyrgeometers for more information.

6.14 Spectral selectivity

Spectral selectivity is the variation of the window transmittance and absorption coefficient of the black detector paint with wavelength and is commonly specified as % of the mean value.

6.15 Environmental

The SGR series are intended for outdoor use under all expected weather conditions. The radiometers comply with IP 67 and their solid mechanical construction is suitable to be used under all environmental conditions within the specified ranges.

6.16 Uncertainty

The measurement uncertainty can be described as the maximum expected hourly or daily uncertainty with respect to the 'absolute truth'. The confidence level is 95%, which means that 95% of the datapoints lie within the given uncertainty interval representing the absolute value. Kipp & Zonen empirically determine uncertainty figures based on many years of field measurements.

7. Maintenance and recalibration

SGR pyrometers are simple to maintain and do not require any special tools or training. There are no service items requiring scheduled replacement.

7.1 Daily maintenance

On clear windless nights the window temperature of horizontally placed radiometers will decrease, even to the dew point temperature of the air, due to infrared radiation exchange with the cold sky. The effective sky temperature can be 30°C lower than the ground temperature.

Depending upon the weather conditions dew, glazed frost or hoar frost can be precipitated on the top of the window and can stay there for several hours in the morning. An ice cap on the window is a strong diffuser and increases the pyrometer signal drastically, up to 50% in the first hours after sunrise. Snow may completely cover the window.

The frequency of cleaning is highly dependent upon the local weather and environmental conditions, such as dust, airborne pollutants or salt spray in marine environments. Ideally, the window of the pyrometer should be cleaned every morning before sunrise. The frequency of cleaning can be reduced by the use of a ventilation unit (less effective for SGR3), with the heaters switched on when necessary.

Note Clean the window using pure alcohol or distilled water and a lint-free cloth. Ensure that no smears or deposits are left on the window.

7.2 Monthly maintenance

Check that the pyrometer is level and adjust if necessary.

Check that the sun shield is firmly clipped on.

7.3 Yearly maintenance

Check all the electrical connections. Unscrew the plugs, clean if necessary and then reconnect.

Check cables for damage caused by accident or by rodents.

Check the instrument mountings and any base supports are secure.

7.4 Calibration

An ideal radiometer gives an output that is proportional to the absolute irradiance level. This relationship can be expressed as a constant ratio called 'sensitivity'. SGR series pyrometers are very stable instruments, but they do change very slightly with time. This is largely due to exposure of the black detector coating to UV solar radiation. Recalibration is recommended every two years. Normally this is carried out at the Kipp & Zonen factory or at an authorised calibration facility.

7.4.1 Calibration principle

An ideal radiometer gives voltage output that is proportional to the absolute irradiance level. This relationship can be expressed as a constant ratio called 'sensitivity' (Sensitivity). The sensitivity figure of a particular pyrometer is unique. In the case of the SGR4 it is determined outdoors by comparison against a reference CGR4 pyrometer. The reference pyrometer is calibrated outdoors regularly at the World Radiation Centre (WRC) at Davos, Switzerland.

Both the SGR3 and SGR4 have an accurate temperature sensor built in. This sensor measures the detector temperature. In the SGR3 this temperature is used to correct for the average temperature dependency of all SGR3's. The SGR4's temperature dependencies are measured individually and corrected for. This same temperature is used to correct for the sensors own radiation and calculate the downward radiation. Both L_{net} and $L_{d\downarrow}$ are available via the Modbus® interface. The analogue output gives $L_{d\downarrow}$ by default, but using the SmartExplorer software this can be changed.

7.4.2 Traceability to World Radiometric Reference

Reference radiometers, which are calibrated annually by the World Radiation Centre in Davos, are used for the calibration of radiometers manufactured by Kipp & Zonen. The reference radiometers are fully characterized, i.e. linearity, temperature dependence and directional response are recorded.

Kipp & Zonen keeps two reference radiometers for each radiometer model. These reference radiometers are sent alternate years to WRC for calibration, so production and calibration in Delft can carry on without interruption.

7.4.3 Recalibration

Radiometer sensitivity changes with time and with exposure to radiation. Periodic calibration every two years is advised. Accurate calibrations can be done outdoors under clear sky conditions by comparison to a reference pyrometer of equal or higher standard.

8. SGR models

The SGR series comprises 2 models, SGR3 and SGR4. The mechanical construction of the SGR3 differs from the SGR4 in that it has a flat silicon window and smaller housing dimensions. Both have non replaceable desiccant. The SGR series is designed for measuring the downward radiation (W/m^2) on a plane surface from the atmosphere above.

SGR4 pyrgeometer includes an integrated bubble level, internal desiccant, white snap-on sun shield, and an optional shielded signal output cable with connector.

SGR4 can be used in conjunction with the Kipp & Zonen CVF4 ventilation unit for enhanced measurement performance and overall reduced instrument maintenance.

For reducing the window heating offset error, the direct solar radiation can be shielded statically from the SGR3 pyrgeometer by the Kipp & Zonen shadow ring CM121, and fully automatically by the SOLYS2 sun tracker with shading system. This can also be done for the SGR4 but is not really necessary because of the minimal window heating effect.

A net pyrgeometer measures both the downward atmospheric long-wave radiation and the upward long-wave radiation from the surface below. It can be configured from two SGR4 series pyrgeometers and a suitable mounting plate. In the case of the SGR3, two instruments can be simply mounted back-to-back and an optional mounting rod fitted.

8.1 SGR4

SGR4 has been designed for scientific measurements outdoors of downward atmospheric long-wave radiation with extremely high reliability and accuracy.

SGR4 provides an output voltage that is proportional to the downward atmospheric long-wave radiation. SGR4 has an integrated temperature sensor to measure the housing temperature.

SGR4 uses a specially designed silicon meniscus window. Although the window is not hemispherical, SGR4 has a 180° field of view with good cosine response. A hard-carbon, diamond-like, coating protects the outer surface of the window and smoothes the spectral response. On the inside, a solar blind interference filter blocks all short-wave solar radiation.

The solar radiation absorbed by the window is conducted away into the housing very effectively, by a unique construction. Even in full sunlight the window heating offset is very low compared to that of other pyrgeometers on the market. This allows accurate daytime measurements without the need for a tracking shading disk. It also eliminates the need for window heating compensation by using the correction formula.

The special features of the SGR4 are:

- Sensitive to infrared radiation in a wavelength from 4.5 to 42 μm .
- Extremely low window heating offset
- 180° field of view with good cosine response
- Diamond-like coating for optimal protection against environmental influences
- Individual measured and corrected temperature dependency of sensitivity
- Direct output of Longwave downward radiation
- Via Modbus® also Net-radiation and Temperature available

8.2 Specifications

Specifications	SGR3	SGR4
Analogue output • V-version	0 to 1V	0 to 1V
Analogue output range ⁽¹⁾	0 to 1000 W/m ²	0 to 1000 W/m ²
Analogue output • A-version	4 to 20 mA	4 to 20 mA
Analogue output range ⁽¹⁾	0 to 1000 W/m ²	0 to 1000 W/m ²
Serial output	RS-485 Modbus®	RS-485 Modbus®
Serial output range ⁽¹⁾	0 to 1000 W/m ²	0 to 1000 W/m ²
Response time (63%)	< 6 s	< 6 s
Response time (95%)	< 18 s	< 18 s
Spectral range (50% points)	4500 to 42000 nm	4500 to 42000 nm
Zero offsets (unventilated) (b) temperature change (5 K/h)	< 5 W/m ²	< 2 W/m ²
Non-stability (change/year)	< 1%	< 1%
Non-linearity (-250 to 250 W/m ²)	< 1%	< 1%
Window heating offset (with 1000 W/m ² direct solar radiation)	< 15 W/m ²	< 4 W/m ²
Temperature response	< 5% (-20 °C to +50 °C) < 5% (-40 °C to +70 °C)	< 1% (-20 °C to +50 °C) < 1% (-40 °C to +70 °C)
Spectral selectivity (8 to 14 μm)	< 5%	< 5%
Tilt response (0° to 90° at ±250 W/m ²)	< 3%	< 1%
Field of view	150°	180°
Accuracy of bubble level	< 0.2°	< 0.1°
Power consumption (at 12VDC)	V-version: 55 mW A-version: 100 mW	V-version: 55 mW A-version: 100 mW
Software, Windows™	Smart Sensor Explorer Software, for configuration, test and data logging	Smart Sensor Explorer Software, for configuration, test and data logging
Supply voltage	5 to 30 VDC	5 to 30 VDC
Detector type	Thermopile	Thermopile
Operating temperature range	-40 °C to +80 °C	-40 °C to +80 °C
Storage temperature range	-40 °C to +80 °C	-40 °C to +80 °C
Humidity range	0 to 100%	0 to 100%
Ingress Protection (IP) rating	67	67

⁽¹⁾ Longwave down radiation

9. Frequently asked questions

The most frequently asked questions are listed below. For an update refer to the Kipp & Zonen website at www.kippzonen.com

Q: What are typical values for downward atmospheric long wave radiation?

A:

Ambient temperature	Overcast sky ($L_{\text{net}} = 0 \text{ W/m}^2$)	Clear sky ($L_{\text{net}} = -150 \text{ W/m}^2$)
	$L_{\text{d}\downarrow}$ in W/m^2	
-20 °C	230	80
0 °C	315	165
+30 °C	480	330

Q: Is the pyrgometer calibration affected by the length of the signal cable?

A: With longer cable lengths the impedance increases, however it does not affect the radiometer sensitivity for the following reason. For the SGR-V the impedance of the voltage measurement device is at least 1000 times more than the impedance of the pyrgometer plus cable. Therefore the current that goes through the readout cable is negligible and won't generate an offset.

For the SGR-A current versions the cable length is limited by the power supply voltage and voltage drop over the cable. However the low cable impedance (150 Ω/km) and normally high impedance of the read-out unit / logger is normally no limitation.

The digital RS-485 output can operate over cable lengths up to 1000 m, depending on the baud-rate used.

10. Trouble shooting

The following contains a procedure for checking the instrument in case it appears that it does not function as it should.

Trouble shooting:

Output signal fails or shows improbable results;

- Check the wires are properly connected to the readout equipment.
- Check the window, it should be clean, use the supplied cleaning cloth to remove dirt, dust or water.
- Check the last calibration date to see if re-calibration, or desiccant replacement is required.

Re-calibration is advised every 2 years.

The desiccant in the SGR lasts for 10 years and is replaced during re-calibration.

- Check levelling (bubble inside ring).

If water or ice is deposited on the window, clean it. Probably water droplets will evaporate in less than one hour under sunlight.

Any visible damage or malfunction should be reported to your distributor, who will suggest appropriate action.

11. Keyword index

Term	Explanation
Albedo	The portion of incoming radiation which is reflected by a surface
Azimuth angle	Angle in horizontal direction (0 to 360°) normally referred to North
Angle of incidence	Incident angle from zenith (0° is vertical, 90° is horizontal)
Cosine response	Radiometer directional response according to the cosine law
Diffuse horizontal irradiance	Solar radiation, scattered by water vapour, dust and other particles as it passes through the atmosphere falling on a horizontal surface (DHI)
Direct normal irradiance	Radiation that has travelled in a straight path from the sun falling on a surface normal to the beam (DNI)
Global horizontal irradiance	Total irradiance falling on a horizontal surface (GHI) Global = Diffuse + (Direct x cos α); α is the solar zenith angle
Irradiance	Radiant flux density (W/m ²)
Long-wave radiation	Radiation with wavelengths from 4 μm to more than 40 μm
Pyranometer	Radiometer for measuring short-wave global radiation
Pyrgeometer	Radiometer for measuring long-wave radiation
Pyrheliometer	Radiometer for measuring direct short-wave radiation
Net radiation	Long-wave downward radiation minus outgoing radiation
Short-wave radiation	Radiation with wavelengths from approximately 300 nm to 4000 nm (4 μm)
Thermopile	Thermal detector made up of many thermocouple junctions
WMO	World Meteorological Organisation, Geneva, Switzerland
WRC	World Radiation Centre, Davos, Switzerland
WRR	World Radiometric Reference (standard radiation scale) at WRC
WSG	World Standard Group of radiometer at WRC
Zenith angle	Angle from zenith (0° is vertical)

Appendices

A. Modbus®

A.1 Modbus® commands

The commands are all according to the Modbus RTU protocols described in the document: ‘Modbus® over serial line V1.02’ and ‘MODBUS application protocol V1.1b’ available from the Modbus® organization (www.modbus.org). The commands can be tested using software tools, such as the program ‘Modbus Poll’ from www.modbustools.com.

The following commands are implemented:

Function	Sub function	Description
0x01	N/A	Read Coils
0x02	N/A	Read Discrete Inputs
0x03	N/A	Read Holding Registers
0x04	N/A	Read Input Register
0x05	N/A	Write Single Coil
0x06	N/A	Write Holding Register
0x10	N/A	Write multiple Registers

The SMP does not make a difference between a ‘coil’ and a discrete input. The only difference is that a discrete input is read only.

The SMP does not make a difference between a holding register and an input register. The only difference is that an input register is read only.

A.2 Input registers

Input registers are read only

Real-time Processed Data						
PDU address	Parameter	Name	R/W	Type	Mode	Description
0	IO_DEVICE_TYPE	DevType	R	U	All	Device type of the sensor
1	IO_DATAMODEL_VERSION	DataSet	R	U	All	Version of the object data model 102=this version
2	IO_OPERATIONAL_MODE	DevMode	R	U	All	Operational mode: normal, service, calibration and so on
3	IO_STATUS_FLAGS	Status	R	U	All	Device Status flags
4	IO_SCALE_FACTOR	Range	R	S	All	Range and scale factor sensor data (determines number of decimal places)
5	IO_SENSOR1_DATA	Sensor1	R	S	N,S	Temperature compensated radiation in W/m ² (Net radiation for SGR)
6	IO_RAW_SENSOR1_DATA	RawData1	R	S	N,S	Net radiation (sensor 1) in W/m ²
7	IO_STDEV_SENSOR1	StDev1	R	S	N,S	Standard deviation IO_SENSOR1_DATA
8	IO_BODY_TEMPERATURE	BodyTemp	R	S	N,S	Body temperature in 0.1 °C
9	IO_EXT_POWER_SENSOR	VSupply	R	S	N,S	External power voltage
10	IO_SENSOR2_DATA	Sensor2	R	S	N,S	Temperature compensated long wave down radiation in W/m ² (only for SGR)
11	IO_RAW_SENSOR2_DATA	RawData2	R	S	N,S	Long wave down radiation in W/m ² (only for SGR)
12	IO_STDEV_SENSOR2	StDev2	R	S	N,S	Not used, always 0
13	IO_BODY_TEMP_K	BodyTempK	R	U	N,S	Body temperature in 0.01 °K (only for SGR)
14	IO_AUX_INPUT2	Aux2	R	S	N,S	Not used, always 0
15	IO_AUX_INPUT3	Aux3	R	S	N,S	Not used, always 0
16	IO_DAC_OUTPUT_VOLTAGE	VDAC	R	U	N,S	DAC output voltage or current (actual voltage or current)
17	IO_SELECTED_DAC_INPUT	DacInp	R	U	N,S	DAC selected input voltage

⁽¹⁾ The scale factor defines the format and number of decimal places

Real-time Data A/D Counts					
PDU address	Parameter	R/W	Type	Mode	Description
18	IO_ADC1_COUNTS	R	S32	All	Input voltage sensor 1 in 0.01 μ V
19					(R18=MSB, R19=LSB)
20	IO_ADC2_COUNTS	R	S32	All	Not supported, always 0
21					
22	IO_ADC3_COUNTS	R	S32	All	Input voltage body temperature sensor in 0.01 μ V
23					(R22=MSB, R23=LSB)
24	IO_ADC4_COUNTS	R	S32	All	Input voltage power sensor in 0.01 μ V
25					(R24=MSB, R25=LSB)

Error reports					
PDU address	Parameter	R/W ⁽²⁾	Type	Mode	Description
26	IO_ERROR_CODE	R	U16	All	Most recent/ actual error code
27	IO_PROTOCOL_ERROR	R	U16	All	Protocol error/communication error
28	IO_ERROR_COUNT_PRI01	R	U16	All	Error code priority 1
29	IO_ERROR_COUNT_PRI02	R	U16	All	Error count priority 2
30	IO_RESTART_COUNT	R	U16	All	Number of controlled restarts
31	IO_FALSE_START_COUNT	R	U16	All	Number of uncontrolled restarts
32	IO_SENSOR_ON_TIME	R	U16	All	On time in seconds (MSB word)
33	IO_SENSOR_ON_TIME_L	R	U16	All	On time in seconds (LSB word)
41	IO_BATCH_NUMBER	R	U16	All	Production batch number
42	IO_SERIAL_NUMBER	R	U16	All	Serial number
43	IO_SOFTWARE_VERSION	R	U16	All	Software version
44	IO_HARDWARE_VERSION	R	U16	All	Hardware version
45	IO_NODE_ID	R	U16	All	(MODBUS®/SMA) device address RS-485

⁽²⁾ Writing any value to input registers 26-33 will reset the contents of the registers

Legend

PDU address	PDU address + 1 = Modbus® register number
Parameter	Name Name of the register
R/W	Read write R Read only R/W Read/write
Type	Type and size U16 16 bit unsigned integer S16 16 bit signed integer S32 32 bit signed integer (MSB first, LSB last)
Mode	Operation mode N available in normal mode S available in service mode C available in calibration mode (not for users) F available in factory mode (not for users) All available in all modes

A.3 Most important registers

In the table below the most important registers from the real-time processed data are combined.

The FL_XXXX registers are six unsigned 2 word integers and six 32 bit floating points and the floating point take two Modbus registers with the Most Significant Byte First.

The IO_SCALE_FACTOR (or Resolution in the SmartExplorer software) influences the floating point registers found in this section.

The registers below are implemented from IO_DATAMODEL_VERSION >= 102

By fetching six registers 10000 to 10005 and six floating point registers from 10006 to 10016, all important sensor information can be collected.

Floating Point Data						
PDU address *	Parameter	Name	R/W	SZ	Mode	Description
10000	U_DEVICE_TYPE		R	U	All	Device type of the sensor (see register IO_DEVICE_TYPE)
10001	U_OPERATIONAL_MODE		R	U	All	Operational mode, normal, service, calibration
10002	U_ERROR_CODE	ErrCode	R	U	All	Most recent/ actual error code (see register IO_ERROR_CODE)
10003	U_STATUS_FLAGS		R	U	All	Device Status flags (see register U_STATUS_FLAGS)
10004	U_BATCH_NR		R	U	All	Production Batch number (see register IO_BATCH_NUMBER)
10005	U_SERIAL_NR		R	U	All	Serial number (see register IO_SERIAL_NUMBER)
10006	FL_SENSOR1_DATA	FSensor1	R	F	All	Temperature compensated (net) radiation sensor 1 in W/m2 with decimal point
10008	FL_STDEV_SENSOR1	FStdDev1	R	F	All	Standard deviation Sensor 1 with decimal point
10010	FL_SENSOR2_DATA	FSensor2	R	F	All	Temperature compensated Long wave down radiation with decimal point
10102	FL_STDEV_SENSOR2	FStdDev2	R	F	All	Not used, always 0
10014	FL_BODY_TEMPERATURE		R	F	All	Body temperature in ° Kelvin with decimal point
10016	FL_EXT_POWER_SENSOR		R	F	All	External power voltage with decimal point

A.4 Holding registers

Device Control					
PDU address	Parameter	R/W	Type	Mode	Description
34	IO_DEF_SCALE_FACTOR	R/W	S16	All	Default scale factor
35 to 40	Factory use only				

A.5 Read input register

Many of the registers and controls are for remote diagnostics. In this chapter only the most interesting registers and controls are described.

Register 0 IO_DEVICE_TYPE

The device type defines which device is connected. This register can be used to check the type of the connected device. IO_datamodel_version 102 supports the following type of sensors.

Real-time Processed Data					
Parameter name	Register	R/W	Initial Val	Mode	Description
IO_DEVICE_TYPE	RO	R	65535	All	Selected device type of the sensor
Parameter	Value	# of sensors	1/Sensitivity	Type	
SMP3 (volt version)	601	1	5-20 $\mu\text{V}/(\text{W}/\text{m}^2)$	Pyranometer	
SMP3 (current loop version)	602	1	5-20 $\mu\text{V}/(\text{W}/\text{m}^2)$	Pyranometer	
SMP6 (volt version)	619	1	7-14 $\mu\text{V}/(\text{W}/\text{m}^2)$	Pyranometer	
SMP6 (current version)	620	1	7-14 $\mu\text{V}/(\text{W}/\text{m}^2)$	Pyranometer	
SMP10 (volt version)	617	1	7-14 $\mu\text{V}/(\text{W}/\text{m}^2)$	Pyranometer	
SMP10 (current version)	618	1	7-14 $\mu\text{V}/(\text{W}/\text{m}^2)$	Pyranometer	
SMP11 (volt version)	603	1	7-14 $\mu\text{V}/(\text{W}/\text{m}^2)$	Pyranometer	
SMP11 (current loop version)	604	1	7-14 $\mu\text{V}/(\text{W}/\text{m}^2)$	Pyranometer	
SMP21 (volt version)	605	1	7-14 $\mu\text{V}/(\text{W}/\text{m}^2)$	Pyranometer	
SMP21 (current loop version)	606	1	7-14 $\mu\text{V}/(\text{W}/\text{m}^2)$	Pyranometer	
SMP22 (volt version)	607	1	7-14 $\mu\text{V}/(\text{W}/\text{m}^2)$	Pyranometer	
SMP22 (current loop version)	608	1	7-14 $\mu\text{V}/(\text{W}/\text{m}^2)$	Pyranometer	
SGR3 (volt version)	609	2*	5-15 $\mu\text{V}/(\text{W}/\text{m}^2)$	Pyrgeometer	
SGR3 (current loop version)	610	2*	5-15 $\mu\text{V}/(\text{W}/\text{m}^2)$	Pyrgeometer	
SGR4 (volt version)	611	2*	5-15 $\mu\text{V}/(\text{W}/\text{m}^2)$	Pyrgeometer	
SGR4 (current loop version)	612	2*	5-15 $\mu\text{V}/(\text{W}/\text{m}^2)$	Pyrgeometer	
SHP1 (volt version)	613	1	7-14 $\mu\text{V}/(\text{W}/\text{m}^2)$	Pyrheliometer	
SHP1 (current loop version)	614	1	7-14 $\mu\text{V}/(\text{W}/\text{m}^2)$	Pyrheliometer	
SUV5 (volt version)	615	1	300 - 500 $\mu\text{V}/(\text{W}/\text{m}^2)$	UV Radiometer	
SUV5 (current loop version)	616	1	300 - 500 $\mu\text{V}/(\text{W}/\text{m}^2)$	UV Radiometer	

Register 1 **IO_DATAMODEL_VERSION**

The data-model describes the functions supported by the smart sensor. This document is valid for data-model version: '102'. A different implementation of the Modbus® protocol (with new features) could result in a different data model 'that is' or 'that is not' compatible with the older version.

The value of this register must be ≥ 102 . If you receive another value then you should read an older or newer version of this document and check the differences.

Register 2 **IO_OPERATIONAL_MODE**

The operation mode defines the state of the smart sensor. The operational modes are 1 = Normal Mode, 2 = Service Mode, 3 = Calibration Mode, 4 = Factory Mode and 5 = Error mode. The standby mode (mode 0) is not supported.

After power on the operation mode (1) is set. When the **IO_CLEAR_ERROR** is set then the smart sensor always returns to the normal mode. When the Error mode (5) is set, then there is a fatal error.

Register 3 **IO_STATUS_FLAGS**

This register defines the status of the smart sensor and the validity of the data. Each bit has a special meaning. Bit 0 is the first (least significant) bit.

Bit 0	Quality of the signal	see IO_VOID_DATA_FLAG
Bit 1	Overflow	see IO_OVERFLOW_ERROR
Bit 2	Underflow	see IO_UNDERFLOW_ERROR
Bit 3	Error flag	see IO_ERROR_FLAG
Bit 4	ADC Error	see IO_ADC_ERROR
Bit 5	DAC Error	see IO_DAC_ERROR
Bit 6	Calibration Error	see IO_CALIBRATION_ERROR
Bit 7	Update EEPROM error	see IO_UPDATE_FAILED

Register 4 **IO_SCALE_FACTOR**

The scale factor defines the number of fractional digits, the range and the position of the decimal point for the following registers: **IO_SENSOR1_DATA**, **IO_SENSOR2_DATA**, **IO_RAW_SENSOR1_DATA** and **IO_RAW_SENSOR2_DATA**. The scale factor is read only. The default value of the scale factor is set during calibration mode or it can be changed during operation (see register **IO_DEF_SCALE_FACTOR** and coil **IO_AUTO_RANGE**).

If the register **IO_SCALE_FACTOR** is not set to 0 then you must multiply or divide the data of register (X), whereas X is one of the above mentioned registers.

Scale factor = 2 (floating point) result = (integer) register (X) / 100.0
Scale factor = 1 (floating point) result = (integer) register(X) / 10.0
Scale factor = 0 (floating point) result = (integer) register(X)
Scale factor = -1 (floating point) result = (integer) register(X) * 10.0

The default value of register **IO_SCALE_FACTOR** is 0. However, this value can be set to a different value if the coil **IO_AUTO_RANGE** is set or a different value is written to the register **IO_DEF_SCALE_FACTOR** (set default scale factor).

Register 5 IO_SENSOR1_DATA

This register holds the actual data (solar radiation) measured by the sensor. The solar radiation is measured in W/m².

If the register **IO_SCALE_FACTOR** is not set to 0 then you must multiply or divide the data as described under register 4.

The raw data from the sensor is calibrated, linearized; temperature compensated and filtered using 2 different kinds of filters (See **IO_FAST_RESPONSE** and **IO_TRACKING_FILTER**).

Register 6 IO_RAW_SENSOR1_DATA

The raw sensor data is calibrated but not linearized and temperature compensated. If the register **IO_SCALE_FACTOR** is not set to 0 then you must multiply or divide the data as described under register 4, **IO_SCALE_FACTOR**.

Register 7 IO_STDEV_SENSOR1

This register is used to calculate the standard deviation over the signal. When the register is read the data is sent to the computer and at the same time a new calculation is started. The next time register 7 is read the standard deviation over the last period is sent to the computer and a new calculation is started. If the poll frequency is quite high (for example 1 poll per second) then the standard deviation will be zero or almost zero, but if the poll frequency is very low then the standard deviation can be quite high, indicating that the data in register 5 or 6 changed dramatically since the last poll. The standard deviation is measured in 0.1 W/m². To convert the data to a floating point, make the following calculation:

(floating point) result = (integer) register (IO_STDEV_SENSOR1) / 10.0

Register 8 IO_BODY_TEMPERATURE

The body temperature sensor measures the temperature of the body in 0.1°C.

The convert the data to a floating point number, make the following calculation:

(floating point) result = (integer) register (IO_BODY_TEMPERATURE) / 10.0

Register 9 IO_EXT_POWER_SENSOR

The Ext power sensor measured the external voltage applied to the sensor in 0.1 Volt.

The convert the data to a floating point number, make the following calculation:

(floating point) result = (integer) register (IO_EXT_POWER_SENSOR) / 10.0

Example

Read registers: 'operational mode to external power' from Modbus® device with address 1.

Tx transmitted data to the smart sensor
 Rx received data from the smart sensor

```
SendModbusRequest (0x04, 1, IO_OPERATIONAL_MODE, 8);
Tx 01 04 00 02 00 08 50 0C
Rx 01 04 10 00 01 00 00 00 03 E5 03 E5 00 00 00 F8 00 EA 66 12
```


Explanation of the received bytes:

- 01 = MODBUS address
- 04 = read input registers
- 10 = number of received data bytes
- 00 01 = operational mode (mode 1)
- 00 00 = status flags (none)
- 00 00 = scale factor = 0 = 1x
- 03 E5 = 997 decimal = sensor 1 data in W/m²
- 03 E5 = 997 decimal = raw sensor 1 data in W/m²
- 00 00 = 0 = standard deviation sensor 1
- 00 F8 = 248 = 24.8 °C.
- 00 EA = 234 = 23.4 Volt
- 66 12 = MODBUS checksum (CRC16)

A.6 Discrete inputs

A discrete input can be true or false. A discrete input is read only; a coil can be read or written.

Status indicators					
Input	Parameter	R/W	Def.	Mode	Description
0	IO_FALSE	R	0	All	Always false (for testing only)
1	IO_TRUE	R	1	All	Always true (for testing only)
2	IO_VOID_DATA_FLAG	R	*	All	Void signal, 1=unstable signal, temperature too low or too high
3	IO_OVERFLOW_ERROR	R	*	All	Overflow, signal out of range
4	IO_UNDEFLOW_ERROR	R	*	All	Underflow signal out of range
5	IO_ERROR_FLAG	R	*	All	General hardware error (set if one of the H/W error flags is set)
6	IO_ADC_ERROR	R	*	All	Hardware error A/D converter
7	IO_DAC_ERROR	R	*	All	Hardware error D/A converter
8	IO_CALIBRATION_ERROR	R	*	All	Calibration checksum error
9	IO_UPDATE_FAILED	R	*	All	Update calibration parameters failed

Legend

Input	Discrete input	Modbus® discrete input 0 is the first discrete input
Coil	Modbus Coil	A coil can be read or written.
Parameter Name	Name of the register	
R/W	Read write	R Read only R/W Read/write
Def	Default value	default value at power on (0, 1 or *) * = undefined
Mode	operation mode	N available in normal mode S available in service mode C available in calibration mode (not for users) F available in factory mode (not for users) All available in all modes

Inputs can be read in all modes but some coils can't be written in normal mode or service mode.

A.7 Coils

Device control					
Coil	Parameter	R/W	Def.	Mode	Description
10	IO_CLEAR_ERROR	R/W	0	All	Select normal operation and clear error (1=clear error)
11 to 17	FACTORY USE ONLY				
18	IO_RESTART_MODBUS	R/W	0	All	Restart the device with modbus® protocol
19	FACTORY USE ONLY				
20	IO_ROUNDOFF	R/W	1	S,N	Enable rounding of sensor data
21	IO_AUTO_RANGE	R/W	0	S,N	Enable auto range mode (0=no auto range)
22	IO_FASTRESPONSE	R/W	0	S,N	Enable fast response filter (0=no filter)
23	IO_TRACKING_FILTER	R/W	1	S,N	Enable tracking filter (0=no filter)

Note The default values of the device options are stored in non-volatile memory. The default values can be overruled during operation. However, at power-on the default values are restored and the smart sensor will start up with the default values stored in the non-volatile memory.

ADC CONTROL					
Coil	Parameter	R/W	Def.	Mode	Description
24 to 34	Factory use only				

A.8 Read write holding registers

Register 34 IO_DEF_SCALE_FACTOR

The default scale factor is set in the factory mode or service mode and is stored in non-volatile memory. The default scale factor stored in non-volatile memory is always set after a power-on. However it is possible to change the default setting during operation by writing a value to the register 34.

Note This value is not stored in non-volatile memory and is overwritten with the default value at power on.

The following values are valid:

Scale factor = 2

Scale factor = 1

Scale factor = 0

Scale factor = -1

Scale factor 0 is the default value. See also input register 4 **IO_SCALE_FACTOR**.

A.9 Read discrete inputs

Discrete input 0 IO_FALSE This discrete input is always false

Discrete input 1 IO_TRUE This discrete input is always true

Discrete input 2 IO_VOID_DATA_FLAG

The void data flag is raised when the data in register **IO_SENSOR1_DATA** or **IO_RAW_SENSOR1_DATA** is not valid, because the body temperature of the sensor is too low or too high, when there is an internal overflow condition, because a calculation is out of range or a division by zero occurred, the reference voltage of the ADC is not stable or the digital filter is not stable. When the **IO_VOID_DATA_FLAG** is set, bit 0 in the **IO_STATUS_FLAGS** is also set.

The **IO_VOID_DATA_FLAG** and bit 0 of the **IO_STATUS_FLAGS** are cleared when the **IO_VOID_DATA_FLAG** is read by the computer.

Discrete input 3 IO_OVERFLOW_ERROR

This discrete input is raised when an out of range condition occurs and the sensor data (see **IO_SENSOR1_DATA**) is above the maximum value specified by the calibration program or above 29,999. The typical maximum value is 4000 W/m².

When the **IO_OVERFLOW_ERROR** is set, bit 1 in the **IO_STATUS_FLAGS** is also set.

The **IO_OVERFLOW_ERROR** and bit 1 of the **IO_STATUS_FLAGS** are cleared when the **IO_OVERFLOW_ERROR** is read by the computer.

Discrete input 4 IO_UNDERFLOW_ERROR

This discrete input is raised when an underflow condition occurs and the sensor data (see **IO_SENSOR1_DATA**) is below the minimum value specified by the calibration program or below -29,999. The typical minimum value is -400 W/m².

When the **IO_UNDERFLOW_ERROR** is set, bit 2 in the **IO_STATUS_FLAGS** is also set.

The **IO_UNDERFLOW_ERROR** and bit 2 of the **IO_STATUS_FLAGS** are cleared when the **IO_UNDERFLOW_ERROR** is read by the computer.

Discrete input 5 IO_ERROR_FLAG

The error flag is raised when there is a (fatal or correctable) hardware error or software error such as: ADC error, DAC error, calibration error or when the update of the calibration data failed. When the **IO_ERROR_FLAG** is raised the error code is copied to the register **IO_ERROR_CODE** (see register 26).

The error flag is cleared when a true condition is written to the coil: '**IO_CLEAR_ERROR**'. This has no effect when the error is fatal or not resolvable such as a calibration error.

The error flag is always set after a power up, this is to indicate the power went off, or a restart occurred. The computer should raise the **IO_CLEAR_ERROR** in order to reset the error flag.

Discrete input 6 IO_ADC_ERROR

This flag is raised when the A/D converter responsible for the conversion of the analogue signals to digital signals detected a failure (hard or software).

The ADC error flag is cleared when a true condition is written to the coil: '**IO_CLEAR_ERROR**' and the error produced by the ADC, is not fatal.

Discrete input 7 IO_DAC_ERROR

This flag is raised when the D/A converter responsible for the conversion of the digital signal to the analogue output signal detected a failure (hard or software).

The DAC error flag is cleared when a true condition is written to the coil: '**IO_CLEAR_ERROR**' and the error produced by the DAC, is not fatal.

Discrete input 8 IO_CALIBRATION_ERROR

The calibration error flag is raised when the sensor was not calibrated or a checksum error was detected in the calibration data. This flag can't be cleared unless the sensor is sent back to the manufacturer or dealer for a re-calibration.

Discrete input 9 IO_UPDATE_FAILED

The update failed is raised when data is written to the non-volatile memory and the update failed. This can happen in calibration mode when calibration data is written to non-volatile memory or in the service mode when device options are written to the non-volatile memory.

If this error is set you should retry the last update action. If the error does not disappear then there could be a hardware problem with the non-volatile memory (EEPROM).

A.10 Read write discrete coils

Coil 10 IO_CLEAR_ERROR

Setting this coil will clear the error only when the error is a non-fatal error. Reading this coil will always return a 0. The coil **IO_CLEAR_ERROR** can be used to select the normal mode (see **IO_OPERATIONAL_MODE**).

The smart sensors will always start-up in the normal mode.

Note Use **IO_CLEAR_ERROR** to return to the normal mode.

Coil 20 IO_ROUNDOff

Setting this coil enables rounding of the data presented in **IO_SENSOR1_DATA** and **IO_RAW_SENSOR1_DATA**.

If not set then the customer should round off the received data before processing the data.

The default value after power on is ON.

If **IO_ROUNDOff** is cleared, then the sensor is not calibrated and could produce more digits, than there are significant digits.

Coil 21 IO_AUTO_RANGE

Setting this coil enables the auto-range feature. The auto-range feature increases the number of digits for small signals

The default value after power on is OFF.

If **IO_AUTO_RANGE** is set then the sensor is not calibrated and could produce more digits, than there are significant digits.

Coil 22 IO_FASTRESPONSE

Setting this coil enables the fast response filter. This filter increases the step response of the sensor. Disabling the fast response give the SMP pyranometers the same response time as the CMP equivalents.

For pyrgeometers the fast response is turned off.

Coil 23 IO_TRACKING_FILTER

Setting to this coil enables the tracking filter. The tracking filter reduces the noise of the signal. However, when the filter is on, the step response on a sudden signal change is decreased. The smart sensor uses variable filter constants to minimize the effect on the step response.

The default value after power on is OFF.

A.11 Requesting serial number

Register 41 IO_BATCH_NUMBER

The batch number defines the production year of the smart sensor, 11 = 2011, 12=2012 etc.

Register 42 IO_SERIAL_NUMBER

Register 42 defines the 4 digits serial number of the smart sensor. Only the combination of the batch number and serial number is unique.

A.12 Simple demonstration program

The simple 'C' program below will show how to read the sensor data and how to deal with errors. The program will read the registers: 'operational mode, status flags, scale factor, and sensor data' from Modbus® device with address 2 into registers uOperationalMode, uStatusFlags, iScaleFactor and iSensorData. Then the program will check the operation mode (must be 'normal') and if there are no errors flags set in iStatusFlags. If there is an error then set the **IO_ERROR_FLAG**.

```
UInt16    uOperationalMode = 0;
UInt16    uStatusFlags = 0;
Int16     iScaleFactor = 0;
Int16     iSensorData = 0;
float     fSensorData = 0;

int main (void)
{
    while (true)
    {
        // Send MODBUS request 0x04 Read input registers to slave 2
        // Get modbus data will wait for the answer and copies the data to registers
        // uOperationalMode, uStatusFlags, iScaleFactor and iSensorData

        SendModbusRequest (0x04, 2, IO_OPERATIONAL_MODE, 4);
        WaitModbusReply ();
        GetModbusData ();

        If (uOperationalMode != 1)
        {
            // Send MODBUS request 0x05 write single coil to slave 2
            SendModbusRequest (0x05, 2, IO_CLEAR_ERROR, true);
            WaitModbusReply ();
        }
        else if (uStatusFlags != 0)
        {
            SendModbusRequest (0x05, 2, IO_CLEAR_ERROR, true);
            WaitModbusReply ();
        }
        switch (iScaleFactor)
        {
            case 2: fSensorData = (float)(iSensorData) / 100.0;
            case 1: fSensorData = (float)(iSensorData) / 10.0;
            case 0: fSensorData = (float)(iSensorData);
            case -1: fSensorData = (float)(iSensorData) * 10.0;
            default: fSensorData = 0.0;
        }
        // wait 1 second
        Delay (1000);
    }
}
```

B. List of World and Regional Radiation Centres

World Radiation Centre

The World Radiation Centre capable of pyrometer calibration is located at:

Physikalisch-Meteorologisches Observatorium

Dorfstrasse 33

CH-7260

Davos Dorf

Switzerland

Website: www.pmodwrc.ch

C. Appendix II Recalibration service

Pyranometers, Albedometers, Pyrgeometers, UV-Radiometers & Sunshine Duration Sensors

Kipp & Zonen solar radiation measurement instruments comply with the most demanding international standards. In order to maintain the specified performance of these instruments, Kipp & Zonen recommends calibration of their instruments every two years.

This can be done at the Kipp & Zonen factory. Here, recalibration to the highest standards can be performed at low cost. Recalibration can usually be performed within four weeks. If required, urgent recalibration can be accomplished in three weeks or less (subject to scheduling restrictions).

Kipp & Zonen will confirm the duration of recalibration at all times. Please note that special quantity recalibration discounts are available for instruments of the same type.



**KIPP &
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SINCE 1830

Our customer support remains at your disposal for any maintenance or repair, calibration, supplies and spares.

Für Servicearbeiten und Kalibrierung, Verbrauchsmaterial und Ersatzteile steht Ihnen unsere Customer Support Abteilung zur Verfügung.

Notre service 'Support Clientèle' reste à votre entière disposition pour tout problème de maintenance, réparation ou d'étalonnage ainsi que pour les accessoires et pièces de rechange.

Nuestro servicio de atención al cliente esta a su disposición para cualquier actuación de mantenimiento, reparación, calibración y suministro de repuestos.

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