SMP10x and SMP22x Smart Pyranometers

Operational Manual

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Subject to technical change.

Table of contents

1 Scope of supply

The following items are included with SMP series pyranometers:

- Smart pyranometer
- Sun shield
- Optional cable, pre-wired with 8-pins connector or connector only for customer cable
- Calibration certificate
- Instruction sheet
- Pyranometer fixing kit SMP10x and SMP22x:
  - 2 stainless steel screws M5 x 80 mm
  - Nuts and flat washers
  - Nylon insulation ring

2 Order numbers and variant code

2.1 Product variants

Variant	Order number
SMP10x	0374950
SMP22x	0374960

2.2 Accessories and spare parts

Accessories

Item	Order number
CVF 4 Ventilation Unit, no plug, no cable	0378910-000
CMF1 Mounting Fixture for 1 or 2 unventilated radiometers	0362700
CMF4 Mounting Fixture	0362703
Glare Screen Kit for downwards facing unventilated radiometers	0305722
Glare Screen Kit for downwards facing ventilated radiometers	0305725
METEON 2.0 Smart Irradiance Meter	0388900
LogBox SE Data Logger	3303096
Fixed Feet	0362705
CM121B Shadow Ring for unventilated radiometers	0346900
CM121C Shadow Ring for ventilated radiometers	0346901
Smart Powered Hub, for up to 6 smart instruments, with integrated AC to 24 V DC power supply	0382440
Smart Hub, for up to 6 smart instruments, for external DC power	0382445
PMU485 Smart Setup Hub	0382460

For SMP10x, SMP22x

Item	Order number
Waterproof 8-pin plug only	2523146
10 m cable, pre-wired with waterproof 8-pin plug	0362621
25 m cable, pre-wired with waterproof 8-pin plug	0362623
50 m cable, pre-wired with waterproof 8-pin plug	0362624
100 m cable, pre-wired with waterproof 8-pin plug	0362625

3 About this manual

3.1 Other applicable documents

The following documents contain further information on installation, maintenance and calibration:

- Smart Explorer Software

3.2 General signs and symbols

The signs and symbols used in the operational manual have the following meaning:

Practical tip

i This symbol indicates important and useful information.

Action

✓ Prerequisite that must be met before performing an action.

▸ Step 1

  ⇨ Intermediate result of an action

▸ Step 2

⇨ Result of a completed action

List

- List item, 1st level
  - List item, 2nd level

3.3 Explanation of warnings

To avoid personal injury and material damage, you must observe the safety information and warnings in this manual. The warnings use the following danger levels:

⚠ **WARNING**

WARNING

This indicates a potentially hazardous situation. If the hazardous situation is not avoided, it may result in death or serious injuries.

⚠ **CAUTION**

CAUTION

This indicates a potentially hazardous situation. If the hazardous situation is not avoided, it may result in moderately serious or minor injuries.

NOTICE

NOTE

This indicates a situation from which damage may arise. If the situation is not avoided, products may be damaged.

4 General safety instructions

4.1 Intended use

The pyranometer is used to measure and report the solar radiation.

4.2 Potential misuse

Any use of the product that does not comply with the intended use, be this intentional or negligent, is forbidden by the manufacturer.

- Use the product only as described in the operational manual.

4.3 Personnel qualification

The equipment described in this manual must be installed, operated, maintained and repaired by qualified personnel only.

- Obtain training from OTT HydroMet if necessary.

4.4 Operator obligations

The installer is responsible for observing the safety regulations. Unqualified personnel working on the product can cause risks that could lead to serious injury.

- Have all activities carried out by qualified personnel.
- Ensure that everybody who works on or with the product has read and understood the operational manual.
- Ensure that safety information is observed.
- File the operational manual together with the documentation of the entire system and ensure that it is accessible at all times.

4.5 Personnel obligations

To avoid equipment damage and injury when handling the product, personnel are obliged to the following:

- Read the operational manual carefully before using the product for the first time.
- Pay attention to all safety information and warnings.
- If you do not understand the information and procedure explanations in this manual, stop the action and contact the service provider for assistance.
- Wear the necessary personal protective equipment.

4.6 Risk of burns due to hot surfaces

If the ambient temperature is too high, the metal parts of the housing may heat up (> 60 °C). Touching the housing can cause burns.

- Do not touch the housing.
- Wear protective gloves during installation and maintenance.

4.7 Correct handling

If the product is not installed, used and maintained correctly, there is a risk of injury. The manufacturer does not accept any liability for personal injury or material damage resulting from incorrect handling.

- Install and operate the product under the technical conditions described in the operational manual.
- Do not change or convert the product in any way.
- Do not perform any repairs yourself.

- Get OTT HydroMet to examine and repair any defects.
- Ensure that the product is correctly disposed of. Do not dispose of it in household waste.

4.8 Certification

CE (EU)
The equipment meets the essential requirements of EMC Directive 2014/30/EU.

FCC (US)
FCC Part 15, Class "B" Limits

This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions:

1. This device may not cause harmful interference.
2. This device must accept any interference received, including interference that may cause undesired operation.

IC (CA)
Canadian Radio Interference-Causing Equipment Regulation, ICES-003, "Class B"

This Class B digital apparatus meets all requirements of the Canadian Interference-Causing Equipment Regulations.

5 Product description

5.1 Design and function

The SMP series instruments are radiometers designed for measuring short-wave irradiance on a plane surface (irradiance, W/m^2) which results from the sum of the direct solar radiation and the diffuse sky radiation incident from the hemisphere above the instrument.

SMP pyranometers feature a 2-wire smart interface with RS-485 Modbus® (RTU) protocol for connection to programmable logic controllers (PLC’s), inverters, digital control equipment and data loggers.

Digital signal processing provides faster response times and, with an integrated temperature sensor, corrects for the temperature dependence of the detector sensitivity. An additional pressure and humidity sensor provides confirmation that the detector remains in stable working condition.

To achieve the required spectral and directional characteristics SMP pyranometers use thermopile detectors and glass domes. The thermopile responds to the total energy absorbed by black surface coating, which is spectrally non-selective. The thermopile warms up and the heat generated flows through a thermal resistance to a heat-sink, the pyranometer housing.

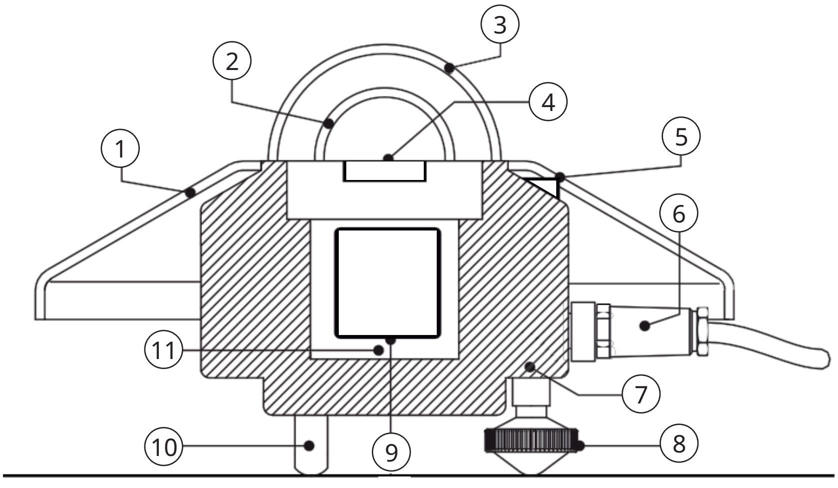
The rise of temperature in the thermopile is easily affected by wind, rain and thermal radiation losses to the environment and the delicate black coating must be protected. Therefore the detector is shielded by domes. These domes allow equal transmittance of the direct solar radiation component for every position of the sun in the hemisphere above the detector. The internal desiccant prevents condensation on the inner sides of the domes, which can cool down considerably on clear windless nights. The pressure and humidity sensor enables desiccant monitoring to clarify that desiccant is not saturated.

The pyranometers have built-in bubble levels and adjustable leveling feet. Snap-on sun shields reduce solar heating of the housings. The waterproof connectors have gold-plated contacts.

Albedometers are constructed by using two pyranometers, an albedometer mounting rod, and a glare screen to prevent direct sunlight from below the horizon entering the lower pyranometer. The upper measures incoming global solar radiation and the lower measures solar radiation reflected from the surface below. The two output irradiance measurements in W/m^2 can be used to calculate the albedo.

The pyranometer can be delivered with an optional waterproof plug pre-wired to a signal cable. Cables are available in 10 m, 25 m, 50 m, or 100 m lengths. The instruments can also be ordered with a plug only, for the user to fit their own cable.

5.2 Product overview



SMP10x, SMP22x pyranometers

1	Sun shield
2	Inner glass dome
3	Outer glass dome
4	Thermopile detector
5	Bubble level
6	Connector
7	Housing
8	Adjustable leveling feet
9	Smart interface
10	Fixed foot
11	Internal desiccant

6 Transport, storage, and unpacking

6.1 Transport

- Transport the product always in its original packaging.
- Ensure that the product is not mechanically stressed during transport.

6.2 Storage

- Store within specified temperature ranges.
- Store in dry area.
- Store in original box where possible.

6.3 Unpacking

- Carefully remove the product from the packaging.
- Check that the delivery is complete and undamaged.
- If you find any damage or if the delivery is incomplete, then immediately contact your supplier or manufacturer.
- Keep the original packaging for any further transportation.

7 Installation

7.1 Planning installation

For the solar irradiation to be measured in the entire photovoltaic system, it is necessary to position several pyranometers in the system. The number of pyranometers required depends on the system's performance and ambient conditions.

The minimum number of sensors required for an IEC 61724-1 Class A monitoring system is defined as follows:

- 1 sensor for each monitoring point to measure the following values:
  - In-plane irradiance (POA)
  - Global horizontal irradiance
- In addition, the following sensors are used for bi-facial performance monitoring:
  - 1 horizontal albedo sensor
    or
  - 3 in-plane rear-side irradiance sensors

The number of monitoring points depends on the system size, as seen in the table below:

System size (AC) in MW	Number of monitoring points	Number of pyranometers
< 40	2	6 to 10
≥ 40 to < 100	3	9 to 15
≥ 100 to < 300	4	12 to 20
≥ 300 to < 500	5	15 to 25
≥ 500 to < 700	6	18 to 30
≥ 700	7, plus 1 for every further 200 MW	21+ to 35+

7.2 Mechanical installation

7.2.1 Preparatory work

- To use the digital output, set the Modbus® address before visiting the site. Otherwise a computer and RS-485 / USB converter is required during installation.

7.2.2 Required tools and aids

The following tools and aids are required:

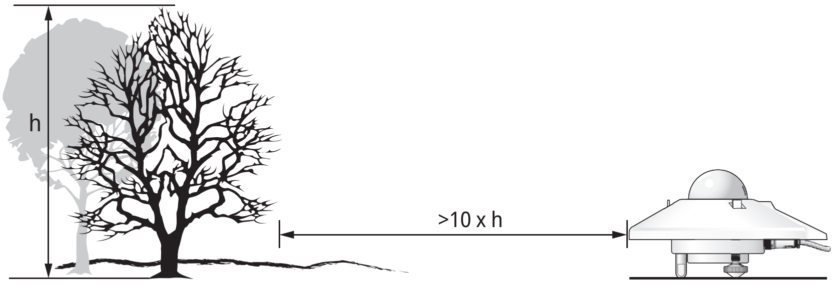
- Allen key, 4 mm
- wrench, 8 mm

7.2.3 Installation for measuring global radiation

7.2.3.1 Choosing a site

There should be no obstructions in the field of view above the instrument's sensor element. If this is not possible, the location of the instrument must be chosen to ensure that obstacles do not rise by more than 5 degrees above the azimuth range between sunrise after the shortest night and sunset on the longest day.

The 5 degrees correspond to a minimum distance from the instrument to the obstacle of 10 times the height of the obstacle:

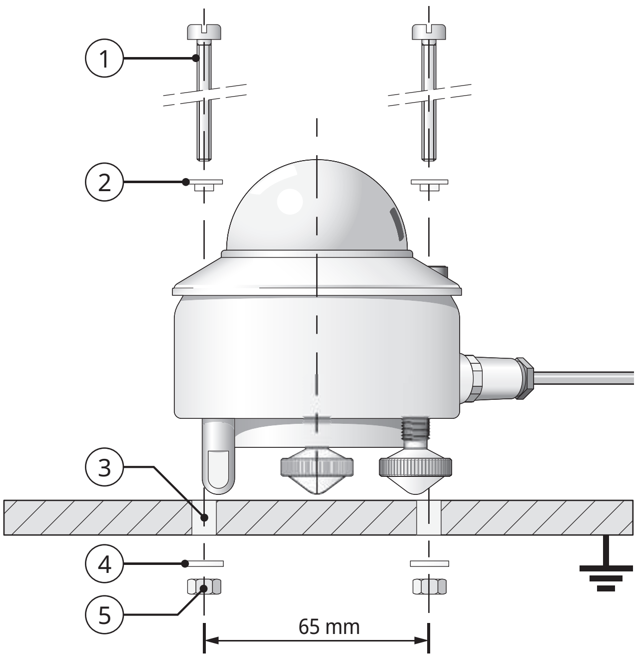


Minimum distance from instrument to obstacle

The minimum distance is important for measuring the direct radiation. The diffuse solar radiation is not so affected by obstacles near the horizon. An obstacle to the field of view that rises 5 degrees over the entire azimuth range of 360 degrees reduces the diffuse radiation directed downwards by only 0.8 %.

- Position the instrument in such a way that no shadows fall on it, for instance from masts.
- Avoid hot exhaust gases with a temperature of over 100 °C in the proximity of the instrument. It can cause measurement deviations.
- Do not position the instrument in front of light-colored walls or any other objects that reflect the sunlight or emit short-wave radiation.

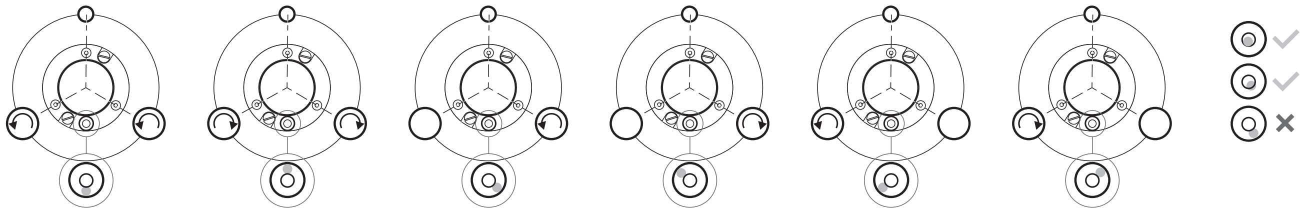
7.2.3.2 Mounting instrument



1	2x M5 x 80 mm screws	4	2x flat washers
2	2x nylon insulating rings	5	2x nuts
3	2x Ø 5.2 mm		

- To insulate the instrument against the temperature of the mounting plate, place the instrument on the fixed foot and the two leveling feet.
- Position the instrument in such a way that the nuts are located at a distance of 2 to 3 mm from the mounting plate.

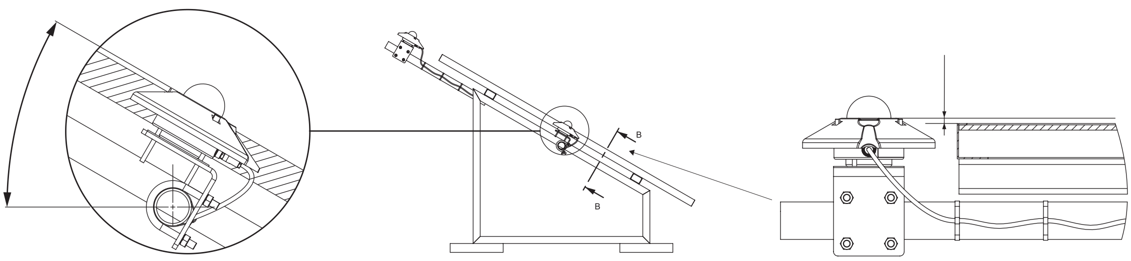
- Ensure that the instrument is fixed.
- Ensure that the instrument is not in the shade.
- When installed horizontally, point the cable connector towards the nearest pole to reduce the UV exposure on the cable.
- In order to align the instrument horizontally, rotate the leveling feet until at least half the spirit level bubble is in the inner ring.



- Fix the instrument with the screws, ensure that the instrument retains the correct alignment.
- To prevent corrosion between the screws and the instrument housing, ensure that the nylon insulating rings are fixed.
- Insert the connector with the cable into the instrument's connection socket.
- Tighten the locking ring hand tight.
  NOTICE! The seal may be damaged by overtightening!
- Fix the cable in such a way that the cable doesn't move or cast a shadow on the instrument.
- Fix the sun shield.

7.2.4 Installation for measuring global radiation on sloping surfaces

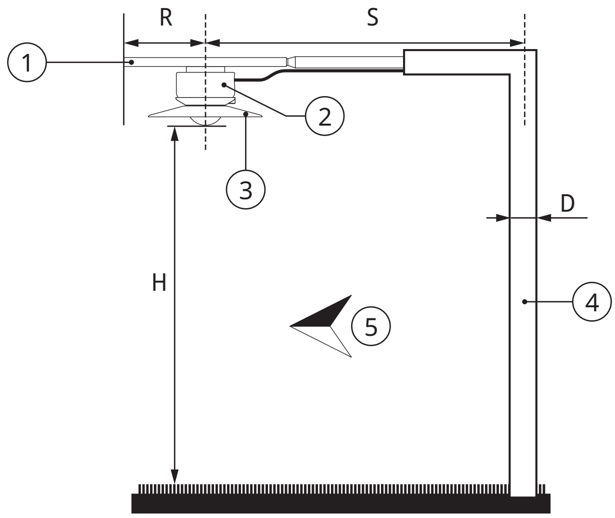
In a photovoltaic system, the pyranometer can be installed at the same angle as the modules. The pyranometer can be mounted using the adjustable leveling feet or using a set of fixed feet that are suitable for mounting on sloping surfaces.



- Place the pyranometer on a horizontal surface.
- Ensure that the leveling feet protrude as far as the fixed foot.
- Level the pyranometer.
- Label the pyranometer with a note stating that the feet have been set.
- Alternatively, remove the leveling feet and mount the fixed feet.
- Label the pyranometer with a note stating that the fixed feet are suitable for sloping installation.
- Fix the pyranometer on the sloping surface.
- Point the cable connector downwards to reduce moisture exposure around the connector.

7.2.5 Installation for measuring reflected radiation

In inverted position the pyranometer measures the reflected global radiation.



1 Mounting plate
2 Pyranometer
3 Glare screen
4 Mast
5 Equator

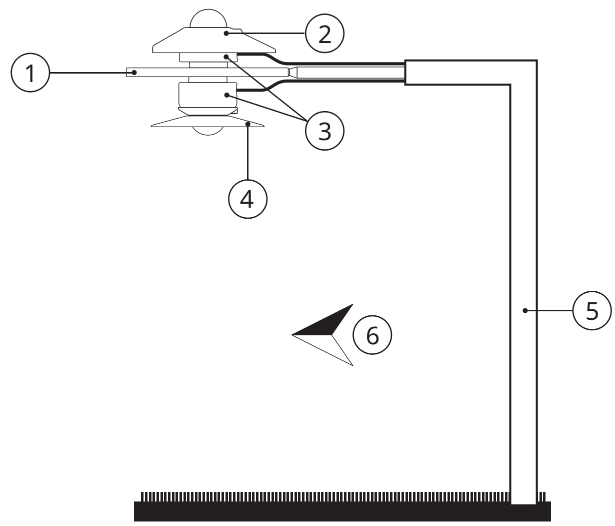
The mounting plate prevents the pyranometer from being heated by solar radiation. The optional glare screen has an angle of 5 degrees and prevents direct radiation on the glass dome during sunrise and sunset.

The mounting device must not excessively disrupt the pyranometer's field of vision. The mast blocks part of the field of view. In addition, depending on the position of the sun, the mast can cast a shadow in the field of the instrument, or it could reflect radiation. In the worst case (sun at its zenith), the pyranometer shadow reduces the signal by a factor of R^2/H^2. As a rule of thumb, a black shadow under the pyranometer with a radius of 0.1 x H reduces the signal by 1%. 99% of the signal comes from a range with a radius of 10 x H.

- Level the mounting plate well, as the pyranometer will be mounted without feet.
- Fix the pyranometer to the mounting plate at a height of between 1 and 2 meters above an even surface such as short grass.

7.2.6 Installation for measuring albedo

An albedometer consists of two identical pyranometers that measure the incident radiation and the radiation reflected by the surface below. Albedo is the ratio of the two radiation measurements and varies from 0 (dark) to 1 (bright).

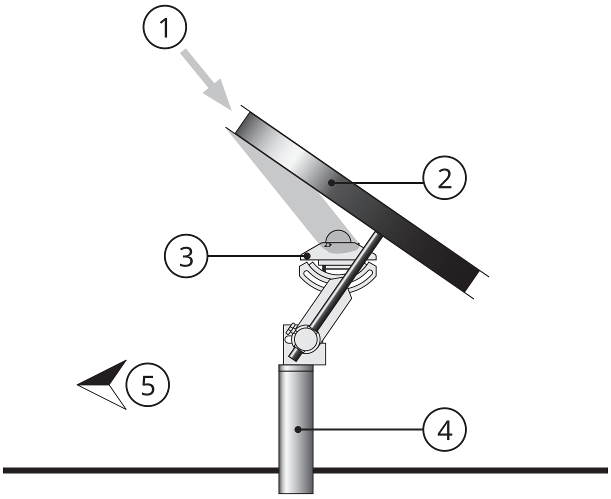


1 Albedo mounting plate
2 Sun shield
3 Pyranometer
4 Glare screen
5 Mast
6 Equator

- Mount the upper pyranometer.
- Mount the lower pyranometer.

7.2.7 Installation for measuring diffuse radiation

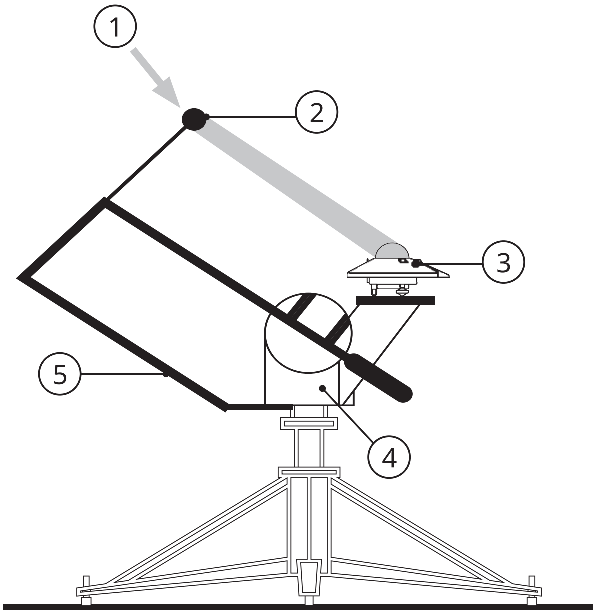
For the diffuse radiation to be measured, the direct radiation on the pyranometer's glass dome must be blocked. The direct radiation can be blocked using a static shadow ring or a two-axis automatic sun tracker.



1 Sun
2 Shadow ring
3 Pyranometer
4 Mounting bracket
5 Equator

Mounting static shadow ring

Because the sun moves across the sky, the static shadow ring interrupts part of the diffuse radiation and needs to be regularly adjusted (every few days). The shadow ring obstructs part of the sky, reducing the amount of diffuse radiation reaching the sensor. The data can be corrected for the obstruction of the sky.



1 Sun
2 Shadow ball
3 Pyranometer
4 Sun tracker
5 Shading assembly

Mounting automatic sun tracker

The automatic sun tracker uses the information regarding its location and the time to calculate the position of the sun. This allows the tracker to be oriented exactly towards the sun whatever the weather. Using a shadowing fixture on the tracker, the pyranometer's glass dome can be shaded all year round without any need for adjustment.

7.3 Electrical installation

7.3.1 Electrical connections

SMP pyranometers can be supplied with a waterproof connector pre-wired to 10 m, 25 m, 50 m, or 100 m of high quality yellow cable with 8 wires and a shield covered with a black sleeve.

Longer cable more than 100 m will affect quality of the RS-485 digital signal. It is recommended to minimize the cable length to ensure reliable communication.

7.3.2 Protective grounding for pyranometer

The shield of the cable is connected to the aluminium pyranometer housing through the connector body.

- Secure the pyranometer with its leveling screws on a metal support (i.e. the instrument mount).
- Ensure there is secure contact between the pyranometer housing and the metal support. The preferred method for protective grounding is to connect the metal support to a local protective ground point (e.g. by using a lightning conductor) and do not connect the cable shield at the readout end.
- If there is no good local protective ground connection at the pyranometer, connect the cable shield to a protective ground point at the readout equipment. Lightning can induce high voltages in the shield but these will be led off at the pyranometer or readout equipment, depending on the connection methodology.

7.3.3 Power connection

The minimum power supply voltage for the instrument is 5 V DC. 5-volt-power can only be used with a short cable, maximum 10 m. To ensure reliable performance, a minimum voltage of 12 V DC is recommended. It is advised to protect the input of the pyranometer with a fast acting overcurrent protection device with a maximum rating of 250 mA.

7.3.4 Power consumption

Typical power consumption SMP10x and SMP22x

Voltage on the pyranometer (V DC)	Current (mA)	Power (mW)
5	10.0	50
12	4.5	55
24	2.5	60

- 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.

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

7.3.5 Wiring information

NOTICE

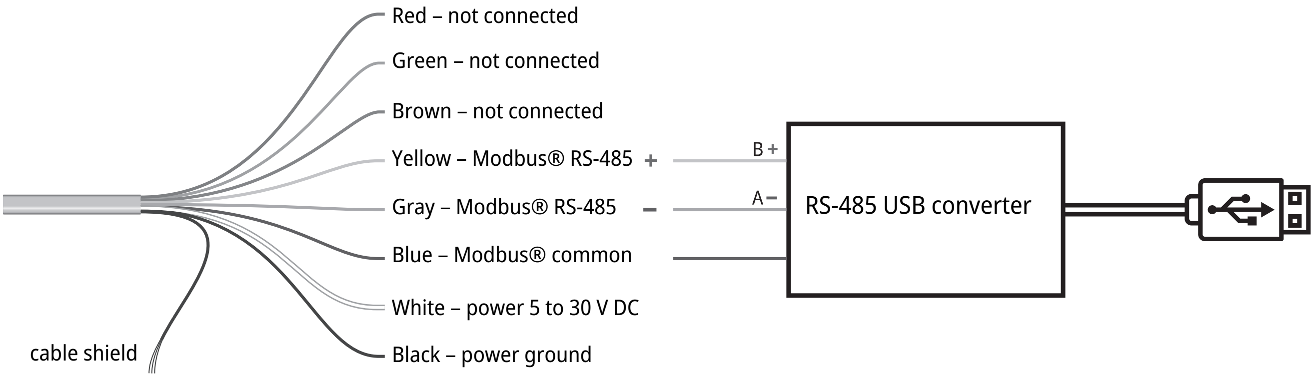
Damage due to lack of insulation!

The power supply units of portable computers such as laptops can generate large voltage peaks.

- Ensure that the RS-485 USB converter has galvanic isolation between the inputs and outputs.

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 V DC.

The instrument must be connected to a computer via an RS-485 converter with a USB port.

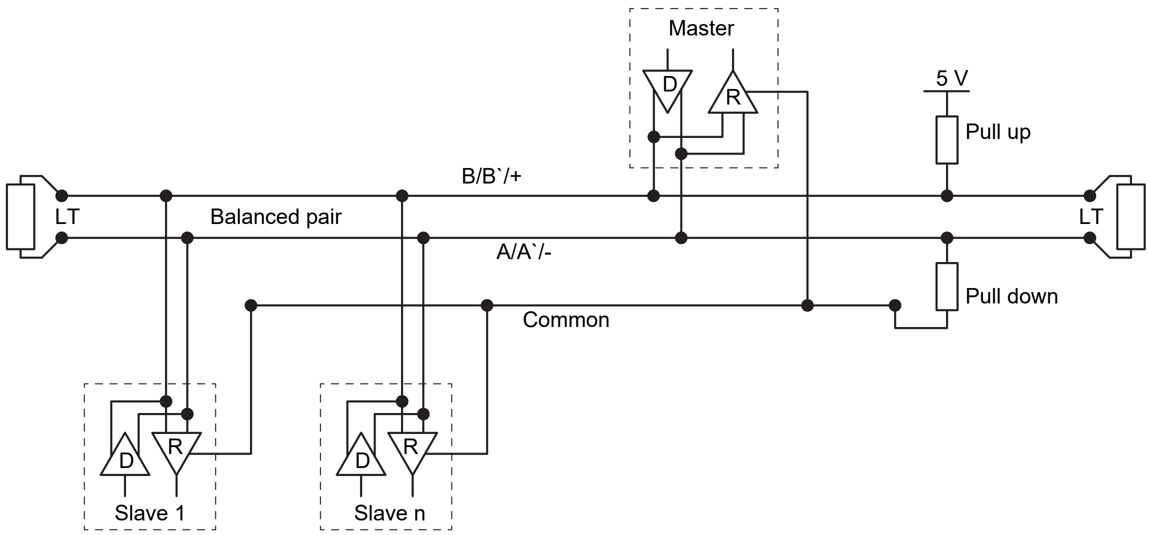


Connection to RS-485 converter

- When connecting the sensor, ensure that the power supply is switched off.
- Connect the white wire and black wire on the power supply unit.
- Connect the yellow, gray and blue wires to the RS-485 converter.
- Isolate and seal the red wire and any other wires when they are not in use.
- Align the indentation on the connector with the indentation on the instruments's connection socket.
- Plug the connector into the connection socket.
- Turn the locking ring clockwise and tighten it hand tight to secure the connector.
  NOTICE! The seal may be damaged by overtightening!
- Switch on the power supply.
- Switch on the computer.

It may take three hours for the pyranometer to reach a stable temperature. During this time, the irradiation measurements may deviate from the final measurements.

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



Connection to a RS-485 network

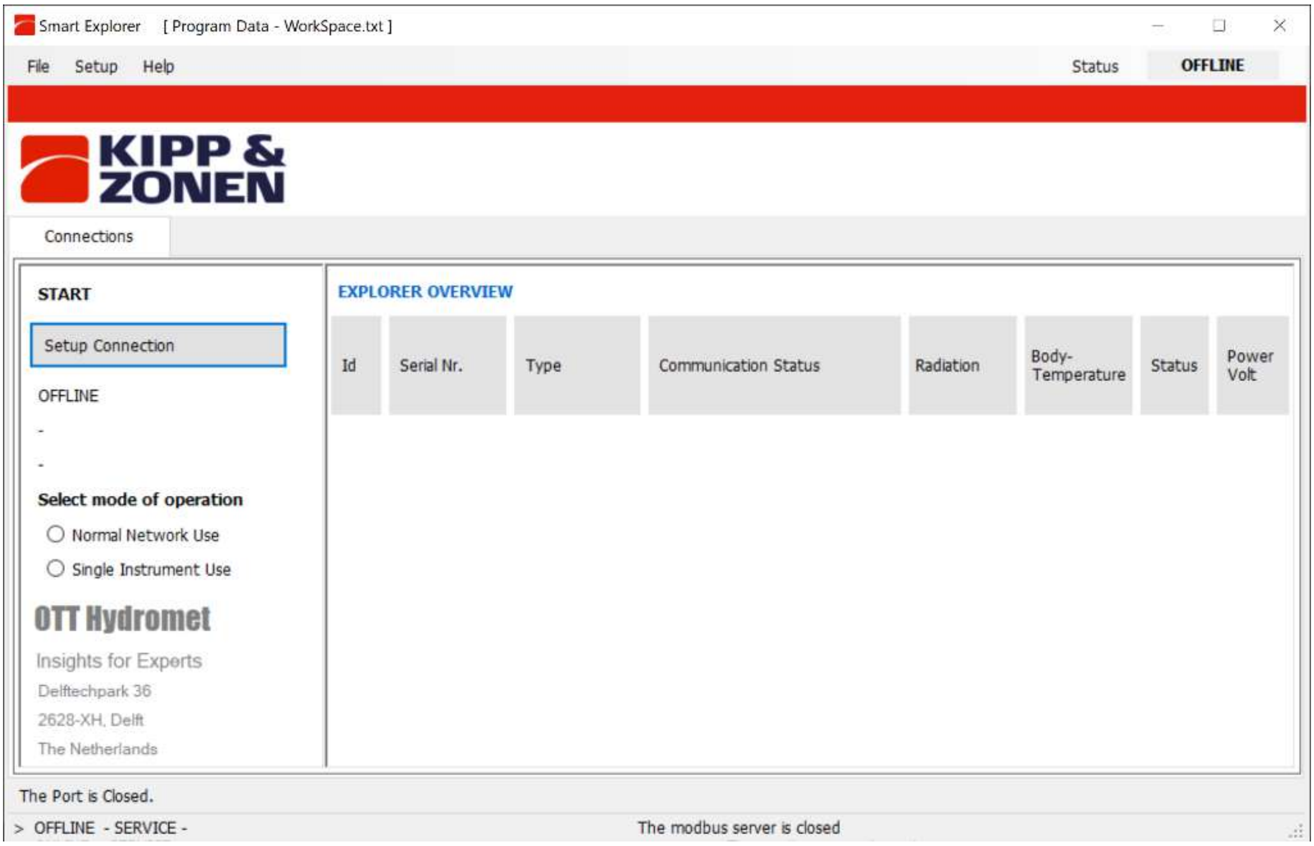
The slaves and master may be a SMP pyranometer or other devices.

- If a SMP pyranometer is the last device on the network, connect a line terminator (LT), consisting of a 120 Ω or 150 Ω resistor, between terminals A/A`/- and B/B`/+.
- Never place this line termination on the derivation cable.
- Install the pull up and pull down resistors as shown, with values between 650 Ω and 850 Ω.

8 Commissioning

8.1 Instrument set-up

The Smart Explorer software allows to configure a smart sensor and to collect real-time data.



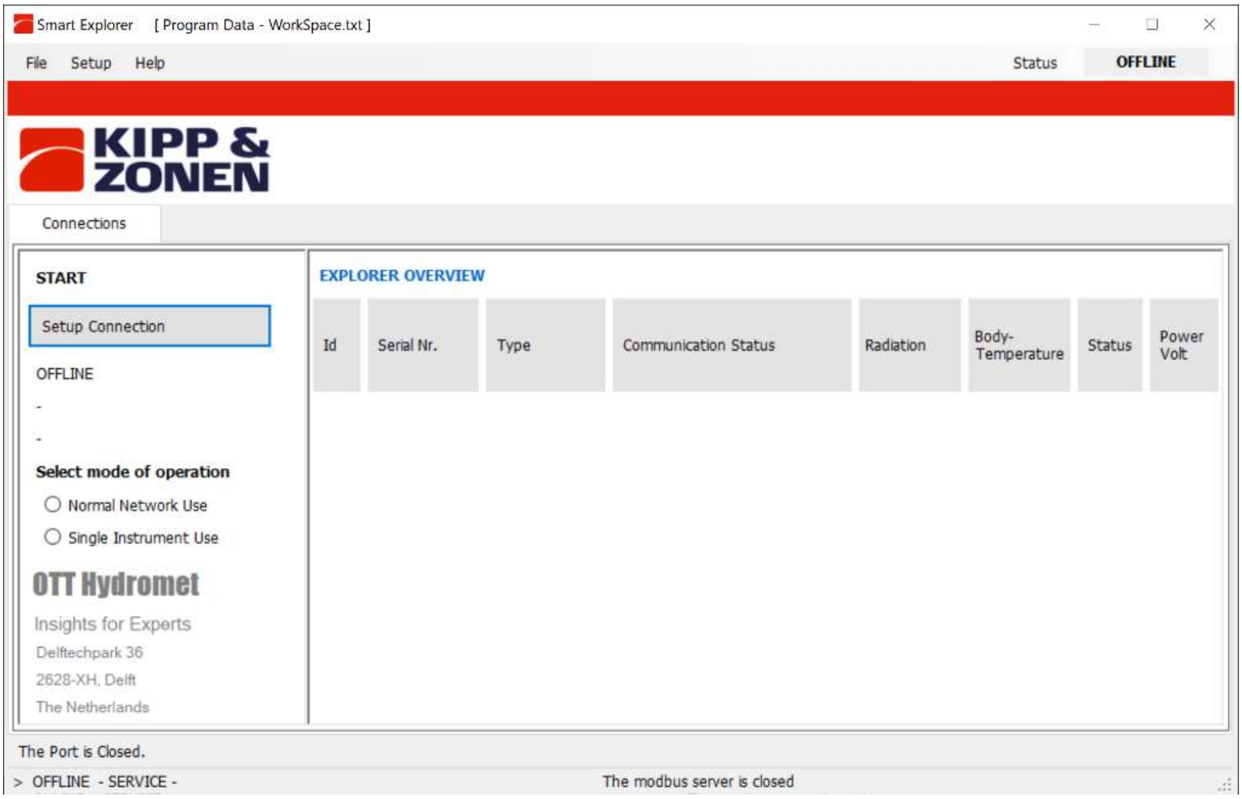
The factory default communication parameters are as follows:

- Modbus® baud rate: 19200
- Parity: even
- Data bits: 8
- Stop bits: 1
- Address: 1

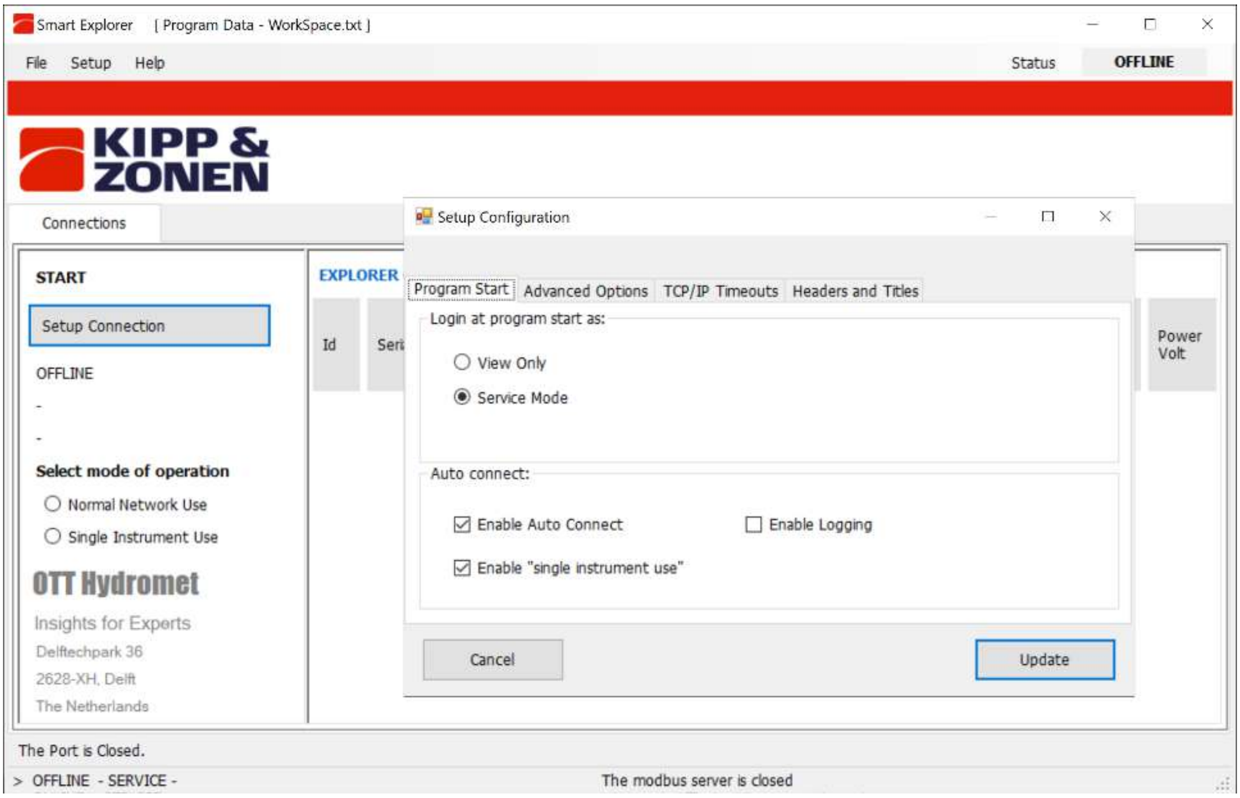
- If using the software on-site, ensure that the software is already installed on the laptop.
- For detailed information about setup, monitoring, and data logging, see the Smart Explore software manual.
- Download the Smart Explorer software and the manual at the following address: www.otthydromet.com

8.1.1 Starting the Smart Explorer Software

- Start the Smart Explorer Software:



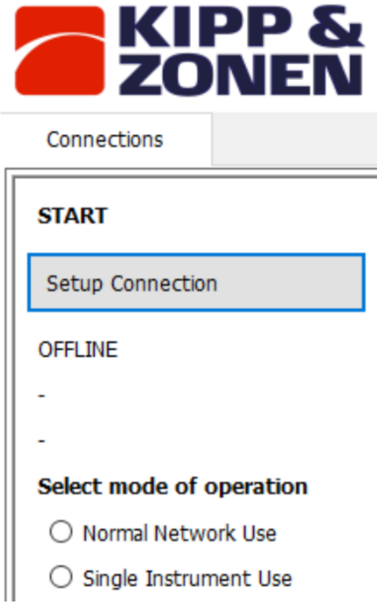
- Click on the *Setup* menu and check whether the following settings are activated:



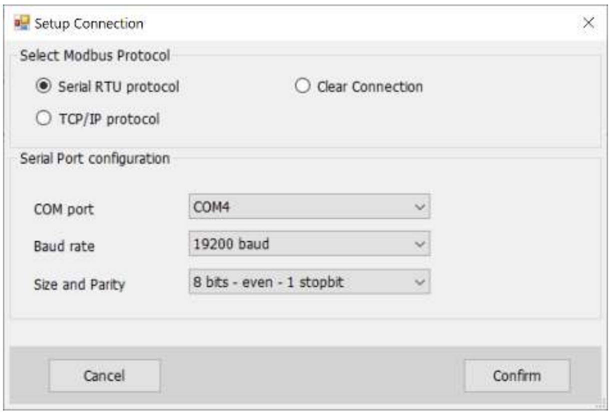
- Adjust the settings if necessary.
- Click on the **Update** button to save the settings.

8.1.2 Establishing connections

- To establish a connection to the instrument, click on the **Setup Connection** button.



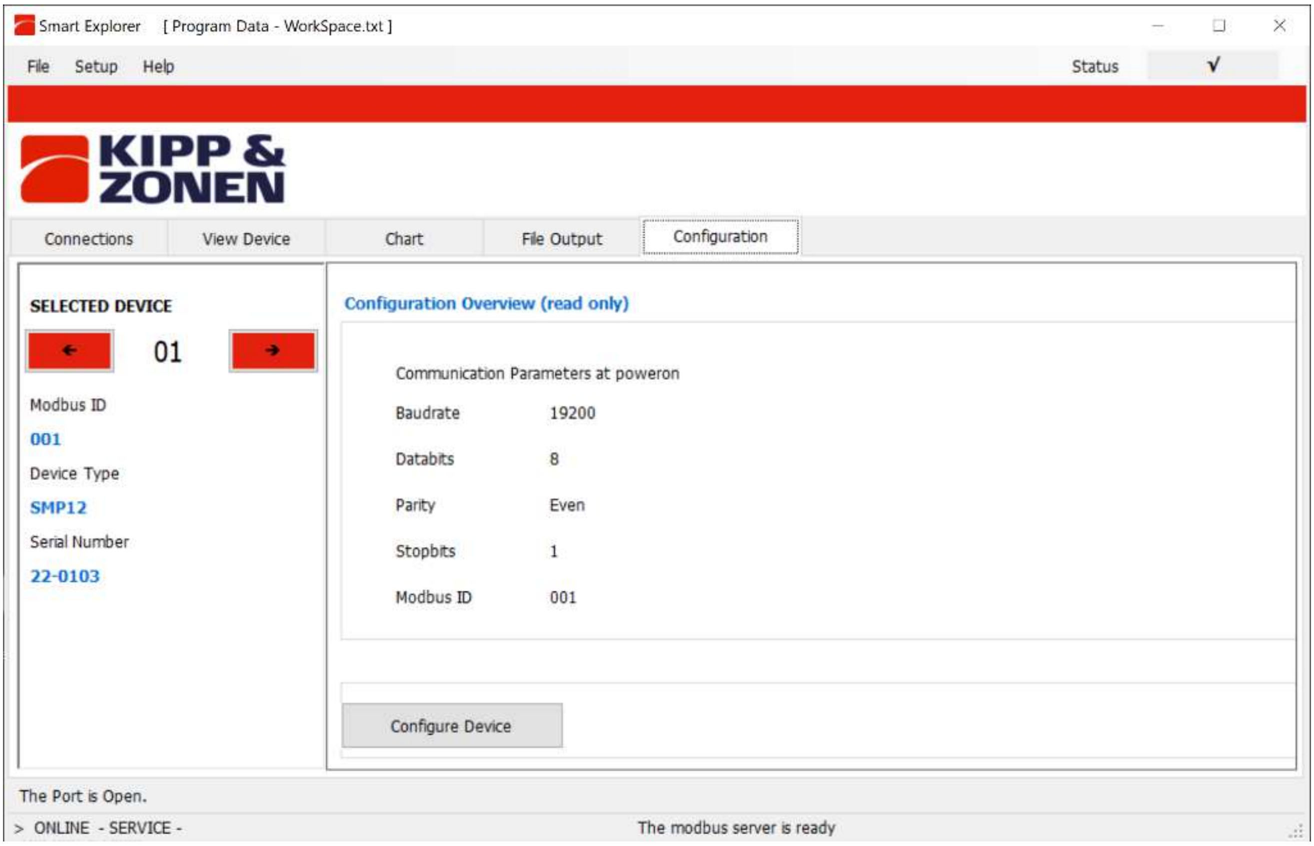
- Activate the *Serial RTU protocol* to establish the direct RS-485 connection.



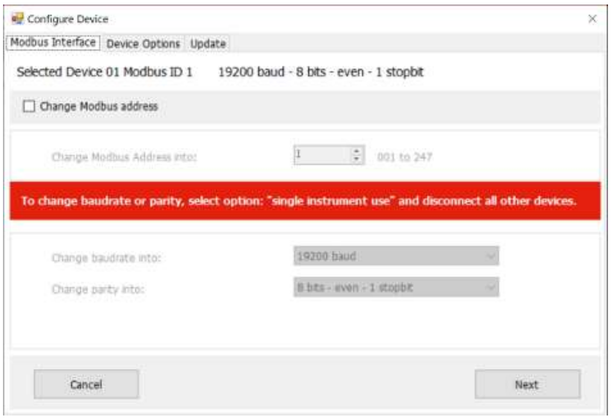
- Select the COM port (see Windows Device Manager).
- Leave the other factory settings unchanged.
- Click on the **Confirm** button to save the settings.

8.1.3 Adjusting the communication parameters

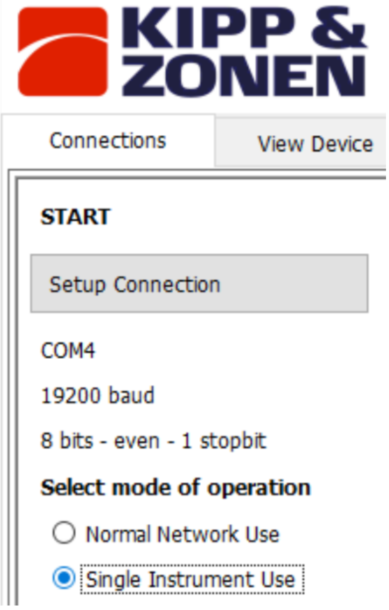
- Click on the *Configuration* tab to access the current communication parameters.



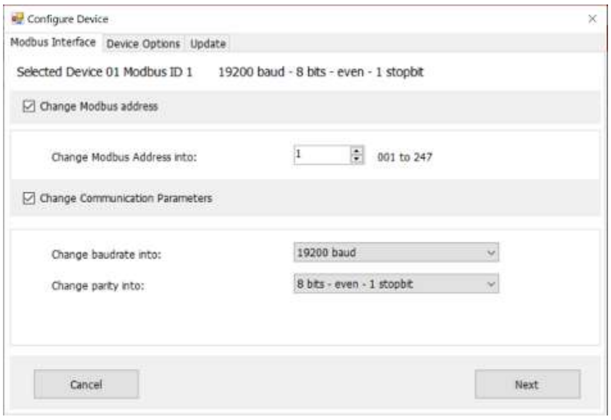
- To change the parameters, click on the **Configure Device** button.
  - ⇨ The following warning appears:



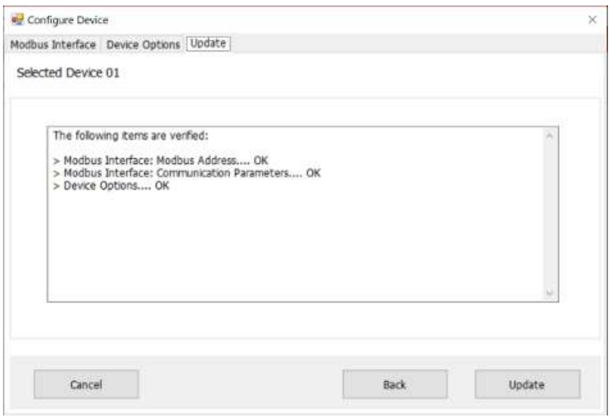
- To change the Modbus address, the baud rate and the parity, close the window and activate the *Single Instrument Use* operating mode on the *Connections* tab. The Modbus address can also be changed in the *Normal Network Use* operating mode.



- Go to the *Configuration* tab and click on the **Configure Device** button again.
- Activate the *Change Modbus address* checkbox and set the new address.



- Activate the *Change Communication Parameters* checkbox and select the baud rate and parity.
- Click on the **Next** button.
  - ⇨ The *Update* tab appears:



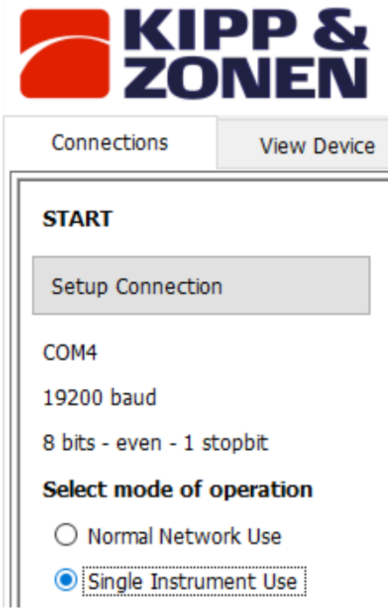
- Click on the **Update** button to save the settings.

⇨ Following the update, the instrument is reset and is ready for operation again after approximately 1 minute.

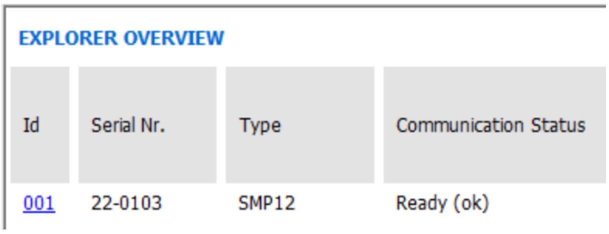
⇨ The communication parameters are changed and the *Connections* tab appears.

8.1.4 Finding an instrument with unknown communication parameters

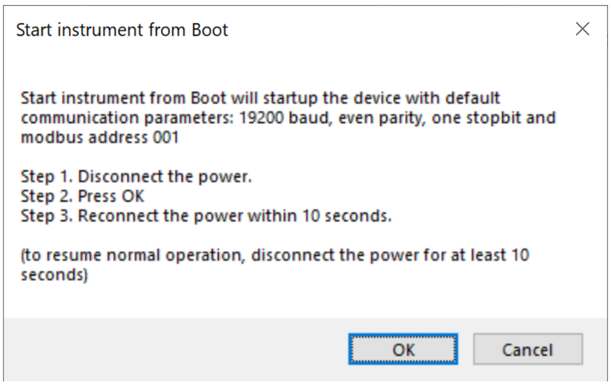
- Activate the *Single Instrument Use* operating mode on the *Connections* tab.



- If only the Modbus address is unknown, click on the **Send Broadcast** button.
  ⇨ The connected instrument is displayed:



- If no instrument is found, click on the **Start From Boot** button.
  ⇨ The following window appears:



- Follow the instructions in the window.
  - ⇨ The connected instrument is displayed:

EXPLORER OVERVIEW

Id	Serial Nr.	Type	Communication Status
001	22-0103	SMP12	Device started from boot

  - ⇨ After approximately 1 minute, reliable measurement results appear on the *Connections* tab.
- Check the communication parameters on the *Configuration* tab.
- Switch off the instrument and switch it back on after 10 seconds to restore normal operation.

9 Operation

9.1 Making and saving measurements

The instruments require suitable sources of power and radiation (light) to operate and make measurements.

- To save the measurements, connect the instrument to a readout or data storage device. The instrument has no internal data memory.

9.2 Collecting data

An optimal setting for the data interval is to sample every second and store one minute averages.

- For setting up the combination of the instrument and data storage read the manual of the data collection device.

10 Maintenance and re-calibration

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

10.1 Maintenance schedule

CAUTION

Risk of burns due to hot surface at high ambient temperature!

The metal parts of the device housing can become very hot at high ambient temperatures (> approx. +60 °C). This can result in burns.

- Do not touch the housing.
- Wear protective gloves during installation and maintenance.

On clear windless nights the outer dome 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 dome and can stay there for several hours in the morning. An ice cap on the dome is a strong diffuser and increases the pyranometer signal drastically, up to 50% in the first hours after sunrise. Snow may completely cover the dome.

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 dome of the pyranometer should be cleaned every morning before sunrise. In all cases the frequency of cleaning can be reduced by the use of a ventilation unit, with the heaters switched on when necessary.

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

For more, the following maintenance intervals are recommended:

Interval	Activity	Performed by
Twice a week	▸ Clean the dome using a dry and lint-free cloth. ▸ For persistent soiling, use additional distilled water. If the soiling is servere, pure alcohol can be used. ▸ Ensure that no streaks or deposits are left on the dome.	Operator
Monthly	▸ Check that the instrument is standing horizontally or at the correct angle. Adjust the instrument if required. ▸ Check that the sun shield is fixed tightly.	Operator
Annually	▸ Check all electrical connections: Unscrew the plugs, clean the plugs if necessary and reconnect. ▸ Check all cables for damage. ▸ Check fastenings and basic supports.	Operator

Interval	Activity	Performed by
	▸ Clean the sun shield if dirty.	
2 years	▸ Perform recalibration to be IEC61724 Class A compliant.	OTT HydroMet
5 years	▸ Have a recalibration performed.	OTT HydroMet
10 years	▸ Replace the desiccant in the instrument.	OTT HydroMet

10.2 Calibration

SMP10x and SMP22x series pyranometers are extremely stable instruments, but like all radiometers, they experience very slightly changes over extended periods of time. This is due to various factors, including prolonged exposure of the black detector coating to UV solar radiation and exposure of the detector to internal humidity that impacts the responsivity.

10.2.1 Re-calibration frequency

The International Electrotechnical Commission (IEC), under the IEC61724-1:2021, defines the requirements for Class A monitoring systems used to monitor photovoltaic systems. For **Class A systems**, as per the IEC61724, all irradiance sensors shall be re-calibrated at least **once every two years**. We recommend re-calibrating at two year intervals to comply with IEC61724 requirements.

Re-calibration of Kipp & Zonen SMP10x and SMP22x should be performed **at least once every five years** of use (from the date of installation) to ensure that the instrument remains within its specified performance parameters.

When the instrument is stored in the dark, in clean dry conditions at room temperature, there is no effect on the sensitivity. Storage periods under these conditions do not count towards the calibration interval. Therefore, instruments kept under such conditions and used only for calibration reference purposes could have longer calibration intervals. However, OTT HydroMet recommends that this should not exceed five years.

10.2.2 Calibration principle

At the OTT HydroMet factory, Kipp & Zonen pyranometers are calibrated, or re-calibrated, in the laboratory according to ISO 9847:2023 'Solar energy - Calibration of field pyranometers by comparison to a reference pyranometer', Annex A 'Calibration devices using artificial sources'. The specific method is detailed in section 6.3.1 'system with a direct beam source (type A1)' and was previously described in the standard as the 'Kipp & Zonen (calibration) device and procedure'.

This method, is based on a side-by-side comparison of the test pyranometer with a reference pyranometer of the same type under a stable artificial sun. The source of light is typically an LED lamp with precise voltage stabilization. The irradiance at the radiometers is approximately 600 W/m^2. The reference pyranometers are regularly calibrated outdoors by OTT HydroMet at a suitable location. While the spectrum of the laboratory calibration lamp differs from the outdoor solar spectrum, this has no consequences for the transfer of calibration, because the reference and test radiometers have the same characteristics/construction.

To minimize stray light from the walls and the operator, the light is restricted to a small cone around the two radiometers. The test radiometer and the reference radiometer are placed side by side on a small rotating table. The lamp is centred on the axis of this table. The table is used to interchange the positions of the pyranometers to allow for inhomogeneity of the light field.

The radiometer positions are interchanged by rotating the table and the whole procedure is repeated. The sensitivity of the test pyranometer is calculated by comparison to the reference pyranometer readings and the calibration certificate is produced. At OTT HydroMet, the complete process is automated under computer control, including programming the SMP pyranometer with the correct calibration factors and default output range settings.

10.2.3 Calibration traceability to the WRR

Our reference pyranometers are calibrated and traceable to the World Radiometric Reference (WRR). They are also fully characterized for linearity, temperature dependence and directional response to enable transfer of the sensitivity under the measurement conditions outdoors to our calibration laboratory conditions.

OTT HydroMet calibration certificates include an overview of the calibration method, details of the reference pyranometer used, traceability to the WRR, and the uncertainty in the full calibration chain from the WRR to the pyranometer being calibrated.

11 Troubleshooting

11.1 Fault elimination

Fault	Possible cause	Measures
Output signal not available or incorrect	Pyranometer does not work properly	▸ Check that the cables are correctly connected to the readout equipment. ▸ Check the power supply (12 V DC recommended). ▸ Check that the instrument has a unique Modbus® address. ▸ Check the location for obstacles that block the direct solar radiation. ▸ Check the glass dome for contamination. Carry out maintenance work as required. ▸ Check that the leveling is correct. ▸ Report any malfunctions or damage to the representative of OTT HydroMet.

12 Repair

12.1 Customer support

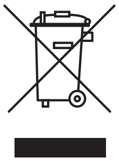
- Have repairs carried out by OTT HydroMet service personnel.
- Only carry out repairs yourself, if you have first consulted OTT HydroMet.
- Contact your local representative: www.otthydromet.com/en/contact-us
- Include the following information:
  - instrument model
  - instrument serial number
  - details of the fault or problem
  - examples of data files
  - readout device or data acquisition system
  - interfaces and power supplies
  - history of any previous repairs or modifications
  - pictures of the installation
  - overview of the local environment conditions

OTT HydroMet repair service

13 Notes on disposing of old devices

Member States of the European Union

In accordance with the German Electrical and Electronic Equipment Act (ElektroG; national implementation of EU Directive 2012/19/EU), OTT HydroMet takes back old devices in the Member States of the European Union and disposes of them in the proper manner. The devices that this concerns are labeled with the following symbol:



- For further information on the take-back procedure contact OTT HydroMet:

OTT HydroMet B.V.
Service & Technical Support
Delftechpark 36
2628 XH Delft
The Netherlands
phone: +31 15 2755 210
email: solar-info@otthydromet.com

All other countries

- Dispose of the product in the proper manner following decommissioning.
- Observe the country-specific regulations on disposing of electronic equipment.
- Do NOT dispose of the product in household waste.

14 Technical data

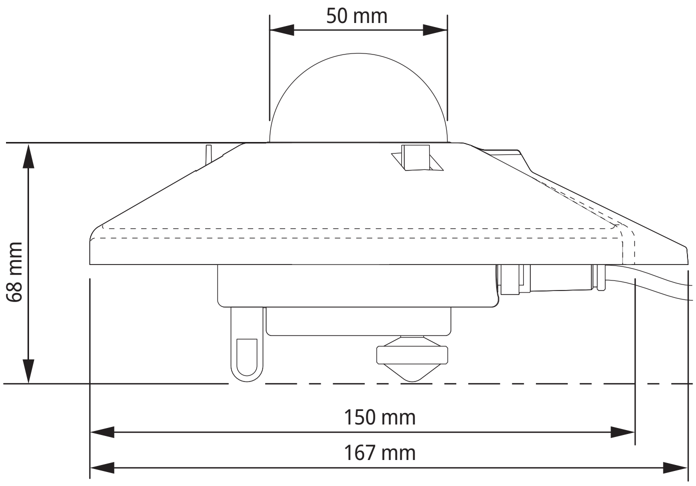
14.1 Optical and electrical data

Specification	SMP10x	SMP22x
Classification to ISO 9060:2018	Spectrally Flat Class A	Spectrally Flat Class A
Serial output	RS-485 Modbus®	RS-485 Modbus®
Serial output range	-400 to 2000 W/m^2	-400 to 2000 W/m^2
Response time (63 %)	< 0.7 s	< 0.7 s
Response time (95 %)	< 2 s	< 2 s
Spectral range (20 % points)	270 to 3000 nm	210 to 3600 nm
Spectral range (50 % points)	285 to 2800 nm	250 to 3500 nm
Zero offset:		
a) thermal radiation (at 200 W/m^2)	< 7 W/m^2	< 5 W/m^2
b) temperature change (5 K/h)	< 2 W/m^2	< 1 W/m^2
c) total zero offset (a, b and other sources)	< 9 W/m^2	< 7 W/m^2
Additional signal processing errors	< 2 W/m^2	< 2 W/m^2
Non-stability (change/5 years)	< 0.5 %	< 0.5 %
Non-linearity (100 to 1000 W/m^2)	< 0.2 %	< 0.2 %
Directional response (up to 80° with 1000 W/m^2 beam)	< 10 W/m^2	< 5 W/m^2
Temperature response	< 0.5 % (-20 °C to +50 °C) < 1 % (-40 °C to +70 °C)	< 0.3 % (-20 °C to +50 °C) < 0.3 % (-40 °C to +70 °C)
Clear sky GHI spectral error	< 0.1 %	< 0.05 %
Spectral selectivity (350 to 1500 nm)	< 3 %	< 3 %
Tilt response (0° to 180° at 1000 W/m^2)	< 0.2 %	< 0.2 %
Field of view	180°	180°
Accuracy of bubble level	< 0.1°	< 0.1°
Power consumption (at 12 V DC)	< 60 mW	< 60 mW
Software, Windows™	SmartExplorer software, for configuration, test and data logging	SmartExplorer software, for configuration, test and data logging
Supply voltage	5 to 30 V DC	5 to 30 V DC
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

Specification	SMP10x	SMP22x
Humidity range (non-condensing)	0 to 100 %	0 to 100 %
MTBF (Mean Time Between Failures)	> 10 years	> 10 years
Ingress Protection (IP) rating	67	67
Recommended applications	High performance for PV panel and thermal collector testing, solar energy research, solar prospecting, materials testing, advanced meteorology and climate networks	Scientific research requiring the highest level of measurement accuracy and reliability under all conditions

i Sensors included for monitoring of desiccant.

14.2 Dimensions and weight



SMP10x, SMP22x

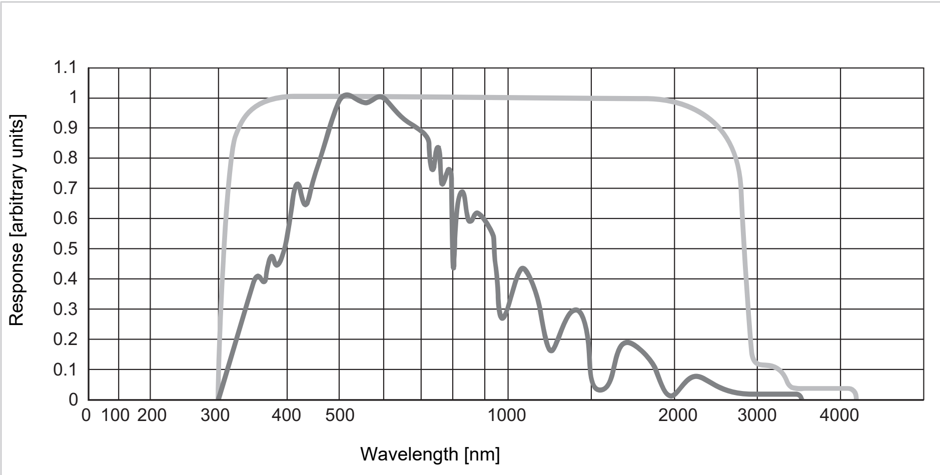
Specification	SMP10x, SMP22x
Instrument weight	600 g
Dimensions unpacked (diameter x height)	15 x 9.3 cm
Packaging dimensions	22,5 x 19 x 15 cm
Weight of 10 m cable	400 g

14.3 Pyranometer properties

Spectral range

The spectrum of the solar radiation reaching the Earth's surface is in the wavelength range between 280 nm and 4000 nm, extending from ultraviolet (UV) to the far infrared (FIR). Due to the excellent physical properties of the glass dome and black absorber paint, Kipp & Zonen SMPx series radiometers are equally sensitive in a wide spectral range. 97 – 98 % of the total energy will be absorbed by the thermal detector.

The following figure shows the solar radiation spectrum and the spectral response of thermopile-type pyranometer.



The solar radiation spectrum at sea level (dark gray solid line)
the spectral response of thermopile-type pyranometer (glass dome) (light gray solid line)

Sensitivity
For the SMP series pyranometers the physical sensitivities are converted to a digital output that is identical for all sensors.

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 changes in the incident radiation. The response time is normally quoted as the time for the output to reach 95 % (sometimes 1/e, 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. SMP series radiometers are set to digitally accelerate the physical response.

Non-linearity
The non-linearity of a pyranometer is the percentage deviation in the sensitivity over an irradiance range from 100 to 1000 W/m^2 compared to the sensitivity calibration irradiance of 500 W/m^2. The non-linear 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.

Temperature dependence
The sensitivity change of the radiometer with ambient temperature change is related to the thermo-dynamics of the radiometer construction. The temperature dependence is given as percentage deviation with respect to the calibrated sensitivity at +20 °C. The SMP series pyranometers have an integrated temperature sensor and use a fourth-order polynominal function to actively correct for temperature errors over a +40 °C to +70 °C range.

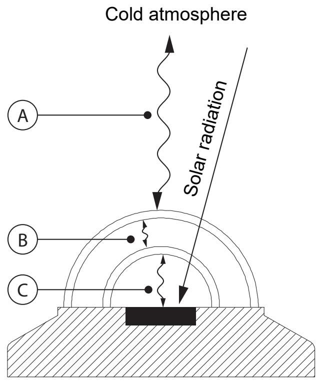
Tilt error
This is the deviation from the sensitivity at 0 ° tilt (exactly horizontal) over the range from 0 ° to 180 ° tilt under 1000 W/m^2 normal incidence irradiance. The tilt response is proportional to the incident radiation. The error could be corrected for, in applications where it is necessary to install the pyranometer on an inclined surface, but is usually insignificant.

Zero offset type A

By physical laws any object having a certain temperature will exchange radiation with its surroundings. The domes of upward facing radiometers will exchange radiation primarily with the relatively cold atmosphere. In general, the atmosphere will be cooler than the ambient temperature at the Earth's surface. For example, a clear sky can have an effective temperature up to 50 °C cooler, whereas an overcast sky will have roughly the same temperature as the Earth's surface.

Due to this the pyranometer dome will 'lose' energy to the colder atmosphere by means of radiative transfer. This causes the dome to become cooler than the rest of the instrument. This temperature difference between the detector and the instrument housing will generate a small negative output signal which is commonly called Zero Offset Type A. This effect is reduced by using an inner dome. This inner dome acts as a 'radiation buffer'.

This offset can be minimized by applying appropriate ventilation of the instrument. The CVF4 ventilation unit can be used with the SMP's.



Thermal exchange between:	
A	Outer dome and atmosphere
B	Inner dome and outer dome
C	Inner dome and detector

Zero offset type B

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.

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. Contact the local representative of OTT HydroMet for further information regarding operation in unusually harsh temperature conditions.

Field of view
The field of view is defined as the unobstructed open viewing angle of a radiometer. ISO and WMO require that a pyranometer for the measurement of global solar radiation has a field of view of 180 ° in all directions (i.e. a hemisphere). The inherent field of view of the instrument should not be confused with the clear field of view of the installation location.

Directional response
Radiation indicent on a flat horizontal surface originating from a point source with a defined zenith position (such as the sun) 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'.

Ideally a pyranometer has a directional response which is exactly the same as the cosine-law. However, in a pyranometer the directional response is influenced by the detector and by the quality, dimensions and construction of the dome(s). The maximum deviation from the ideal cosine-response of the pyranometer is given up to 80 ° angle of incidence with respect to 1000 W/m^2 irradiance at normal incidence (0 ° zenith angle).

Maximum irradiance
The maximum irradiance is defined as the total irradiance level beyond which the output is no longer linear and out of specifications. The measurement range of the irradiance for the SMPx is set to 2000 W/m^2, which is sufficient under normal atmospheric conditions. For special applications (environmental test rooms) the SMP's can be set higher, up to 4000 W/m^2.

Non-stability
This is the percentage change in sensitivity over a period of five years. This effect is mostly due to degradation by UV radiation of the black absorber coating on the thermopile surface.

For solar PV applications, the IEC61724-1:2021 standard mandates that sensors in Class A monitoring systems be re-calibrated at least every two years, unless the manufacturer advises more frequent checks. Kipp & Zonen instruments, however, require recalibration only every five years if maintained properly. Instruments stored in clean, dry, dark conditions with regularly changed desiccant, can have extended calibration intervals, though five years remains the recommended maximum.

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

Environmental
The SMP series are intended for outdoor use under all expected weather conditions. The radiometers comply with IP67 and their solid mechanical construction is suitable to be used under all environmental conditions within the specified ranges.

Uncertainty
The measurement uncertainty of a pyranometer 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 data-points lie within the given uncertainty interval representing the absolute value. OTT HydroMet empirically determines uncertainty figures based on many years of field measurements for typical operating conditions.

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

For a 'High Quality' pyranometer the WMO expects maximum uncertainty in the hourly radiation totals of 3 %. In the daily total an uncertainty of 2 % is expected, because some response variations cancel each other out if the integration period is long. See the WMO 'Guide to Meteorological Instruments and Methods of Observation' Seventh Edition, 2008. ISO 9060:2018 does not refer to hourly or daily uncertainties.

Many years of experience has shown that pyranometer performance can be improved concerning zero offset type A by using a well-designed ventilation system. The Kipp & Zonen CVF4 ventilation unit is recommended for the SMP's to minimize this small error.

15 Appendix

15.1 Commonly used 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 series devices do not make a difference between a “coil” and a “discrete input”. The only difference is that a discrete input is read only. The SMP series devices do not make a difference between a holding register and an input register. The only difference is that an input register is read only.

15.2 Input registers overview

Input registers are read only.

Real-time processed data

PDU address	Parameter	R/W	Type	Mode	Description
0	IO_DEVICE_TYPE	R	U16	All	Device type of the sensor
1	IO_DATAMODEL_VERSION	R	U16	All	Version of the object data model
2	IO_OPERATIONAL_MODE	R	U16	All	Operational mode: normal, service, calibration, and factory
3	IO_STATUS_FLAGS	R	U16	All	Device status flags
4	IO_SCALE_FACTOR	R	S16	All	Scale factor for sensor data (determines number of decimal places)
5	IO_SENSOR1_DATA	R	S16	N, S	Temperature compensated radiation in W/m^2 (Net radiation for SGR) (1)
6	IO_RAW_SENSOR1_DATA	R	S16	N, S	Raw, non-linearized and non-temperature compensated radiation(1)
7	IO_STDEV_SENSOR1	R	S16	N, S	Standard deviation IO_SENSOR1_DATA
8	IO_BODY_TEMPERATURE	R	S16	N, S	Body temperature in 0.1 °C
9	IO_EXT_POWER_SENSOR	R	S16	N, S	External power voltage
10	IO_SENSOR2_DATA	R	S16	N, S	Temperature compensated long wave down radiation in W/m^2 (only for SGR) (1)

PDU address	Parameter	R/W	Type	Mode	Description
11	IO_RAW_SENSOR2_DATA	R	S16	N, S	Long wave down radiation in W/m^2 (only for SGR) (1)
12	IO_STDEV_SENSOR2	R	S16	N, S	Not used, always 0
13	IO_TEMP_SENSOR_1_K	R	U16	N, S	Body temperature in 0.01 °K (only for SGR)
14	IO_TEMP_SENSOR_2_K	R	U16	N, S	Panel temperature in 0.01 °K (only for DustIQ and RT1)
16	IO_RH	R	U16	All	Internal relative humidity of the sensor in 0.1 %
17	IO_PRESSURE	R	U16	All	Internal pressure of the sensor in hPa

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

R = Read only | U16 = 16-bit unsigned integer | S16 = 16-bit signed integer | N = available in normal mode | S = available in service mode

Real-time data A/D counts

PDU address	Parameter	R/W	Type	Mode	Description
90	IO_ADC1_COUNTS	R	S32	All	Input voltage sensor 1 in 0.01 μV
91	–	–	–	–	(R18=MSB, R19=LSB)
92	IO_ADC2_COUNTS	R	S32	All	Not supported, always 0
93	–	–	–	–	–
94	IO_ADC3_COUNTS	R	S32	All	Input voltage body temperature sensor in 0.01 μV
95	–	–	–	–	(R22=MSB, R23=LSB)
96	IO_ADC4_COUNTS	R	S32	All	Input voltage power sensor in 0.01 μV
97	–	–	–	–	(R24=MSB, R25=LSB)

R = Read only | S32 = 32-bit signed integer | All = available in normal and service mode

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_PRIO1	R	U16	All	Priority 1 error count
29	IO_ERROR_COUNT_PRIO2	R	U16	All	Priority 2 error count
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_TIMEH	R	U16	All	On time in seconds (MSB word)
33	IO_SENSOR_ON_TIMEL	R	U16	All	On time in seconds (LSB word)
41	IO_BATCH_NUMBER	R	U16	All	Production batch number = year in YY
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

PDU address	Parameter	R/W[2]	Type	Mode	Description
45	IO_NODE_ID	R	U16	All	(Modbus®) device address RS-485

[2] Writing any value to input registers 26-33 will reset the contents of the registers

R = Read only | U16 = 16-bit unsigned integer | All = available in normal and service mode

Real time floating data points

PDU address	Parameter	R/W[2]	Type	Mode	Description
10000	U_DEVICE_TYPE	R	U16	All	Device type of the sensor (see register IO_DEVICE_TYPE)
10001	U_OPERATIONAL_MODE	R	U16	All	Operational mode (see register IO_OPERATIONAL_MODE)
10002	U_ERROR_CODE	R	U16	All	Most recent/actual error code (see register IO_ERROR_CODE)
10003	U_STATUS_FLAGS	R	U16	All	Device status flags (see register U_STATUS_FLAGS)
10004	U_BATCH_NR	R	U16	All	Production Batch number (see register IO_BATCH_NUMBER)
10005	U_SERIAL_NR	R	U16	All	Serial number (see register IO_SERIAL_NUMBER)
10006	FL_SENSOR1_DATA	R	F32	All	Temperature compensated radiation 1 in W/m^2
10008	FL_STDEV_SENSOR1	R	F32	All	Standard deviation sensor 1
10010	FL_ SENSOR2_DATA	R	F32	All	Temperature compensated radiation sensor 2 or long wave down.
10012	FL_STDEV_SENSOR2	R	F32	All	Not used. Always 0
10014	FL_BODY_TEMPERATURE	R	F32	All	Body temperature
10016	FL_EXT_POWER_SENSOR	R	F32	All	External power voltage
10018	F_PVPANEL_TEMP_K	R	F32	All	PV panel temperature
10020	FL_TILT	R	F32	All	Averaged tilt of the sensor in the horizontal plane in °
10022	FL_RH	R	F32	All	Internal relative humidity of the sensor in %
10024	FL_PRESSURE	R	F32	All	Internal pressure of the sensor in hPa
10026	FL_ROLL	R	F32	All	Averaged roll of the sensor in °
10028	FL_PITCH	R	F32	All	Averaged pitch of the sensor in °

R = Read only | U16 = 16-bit unsigned integer | F32 = 32-bit floating point | All = available in normal and service mode

15.3 Holding registers overview

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

R/W = Read/Write | S16 = 16-bit signed integer | All = available in normal and service mode

15.4 Discrete inputs overview

Status indicators

Input	Parameter	R/W	Default	Mode	Description
0	IO_SENSOR1_DISCONNECTED	R	0	All	Sensor 1 disconnected
1	IO_SENSOR2_DISCONNECTED	R	0	All	Sensor 2 disconnected
2	IO_VOID_DATA_FLAG	R	0	All	Void signal, 1 = unstable signal, temperature too low or too high
3	IO_OVERFLOW_ERROR	R	1 (1)	All	Overflow, signal out of range
4	IO_UNDEFLOW_ERROR	R	1 (1)	All	Underflow signal out of range
5	IO_ERROR_FLAG	R	1 (1)	All	General hardware error (set if one of the H/W error flags is set)
6	IO_ADC_ERROR	R	1 (1)	All	Hardware error A/D converter
7	IO_DAC_ERROR	R	1 (1)	All	Hardware error D/A converter
8	IO_CALIBRATION_ERROR	R	1 (1)	All	Calibration checksum error
9	IO_UPDATE_FAILED	R	1 (1)	All	Update parameters stored in nonvolatile memory failed

(1) Set if an error occurred at power on, otherwise cleared.

A discrete input can be true or false. A discrete input is read only and can be read in all modes.

15.5 Discrete coils overview

Device control

Coil	Parameter	R/W	Default	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_ROUND	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)
24	IO_CLAMP_IRR	R/W	0	S, N	Enable irradiance clamping (0 = no clamping, 1 = prohibit negative values)

R/W = Read/Write | N = available in normal mode | S = available in service mode | All = available in normal and service mode
A coil can be read, but some can't be written in normal mode or service mode.

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.

Input	PDU Address + 1 = Modbus® register number		
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
		ALL	Available in all modes

Inputs can be read in all modes but some coils cannot be written to in normal or service mode

15.6 Input register details

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

Register	Parameter	Description		
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 108 supports the following type of sensors:		
		SMP10x	635	1
		SMP22x	636	1
1	IO_DATAMODEL_VERSION	The data-model describes the functions supported by the smart sensor. This document is valid for data-model version: 108. 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 >=108. If you receive another value, then you should read an older or newer version of this document and check the differences.		
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	
		5	Error mode	
		After power on the normal mode (1) is set. When the IO_CLEAR_ERROR is set then the smart sensor always returns to the normal mode (1). When the error mode (5) is set, then there is a fatal error.		
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.		

Register	Parameter	Description		
		Bit #	*Parameter*	*Descriptions*
		0	IO_VOID_DATA_FLAG	Invalid data
		1	IO_OVERFLOW_ERROR	Overflow condition
		2	IO_UNDERFLOW_ERROR	Underflow condition
		3	IO_ERROR_FLAG	Error
		4	IO_ADC_ERROR	ADC Error
		5	IO_DAC_ERROR	DAC Error
		6	IO_CALIBRATION_ERROR	Calibration checksum error
		7	IO_UPDATE_FAILED	Update of parameters stored in nonvolatile memory failed
		8	POWER_FAILED_FLAG	A power failure occured
		9	N/A	N/A
		10	IO_RH_ERROR	Relative humidity sensor error
		11	Desiccant warning flag	Desiccant saturation warning
		12	Body temperature sensor error	see IO_BODY_TEMP_ERROR
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 a copy of register 34 IO_DEF_SCALE_FACTOR, made during power up. If the register IO_SCALE_FACTOR is not set to 0 then you must multiply or divide the data of the above mentioned four IO_SENSOR registers.		
		Scale factor	*Calculation*	
		2	floating point result = integer register X / 100	
		1	floating point result = integer register X / 10	
		0	floating point result = integer register X	
		-1	floating point result = integer register X * 10	
5	IO_SENSOR1_DATA	This register holds the actual data (solar radiation) measured by the sensor. The solar radiation is measured in W/m^2. 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.		
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.		
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		

Register	Parameter	Description
		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/m^2. To convert the data to a floating point, make the following calculation: floating point result = integer register (IO_STDEV_SENSOR1) / 10
8	IO_BODY_TEMPERATURE	The body temperature sensor measures the temperature of the body in 0.1 °C. To convert the data to a floating-point number, make the following calculation: floating point result = integer register (IO_BODY_TEMPERATURE) / 10
9	IO_EXT_POWER_SENSOR	The external power sensor measures the external voltage applied to the chassis socket in 0.1 Volt. To convert the data to a floating-point number, make the following calculation: floating point result = integer register (IO_EXT_POWER_SENSOR) / 10
15	IO_TILT	The tilt sensor measures the tilt of the sensor in the horizontal plane in 0.1°. To convert the data to a floating-point number, make the following calculation: floating point result = integer register (IO_TILT) / 10
16	IO_RH	The RH sensor measures the internal relative humidity of the sensor in 0.1 hPa. To convert the data to a floating-point number, make the following calculation: floating point result = integer register (IO_RH) / 10
17	IO_PRESSURE	The pressure sensor measures the internal pressure of the sensor in 0.1 hPa. To convert the data to a floating-point number, make the following calculation: floating point result = integer register (IO_PRESSURE) / 10
18	IO_ROLL	The tilt sensor measures the roll of the sensor in 0.1 %. To convert the data to a floating-point number, make the following calculation: floating point result = integer register (IO_ROLL) / 10
19	IO_PITCH	The tilt sensor measures the pitch of the sensor in 0.1 %. To convert the data to a floating-point number, make the following calculation: floating point result = integer register (IO_PITCH) / 10

15.7 Holding register details

Register	Parameter	Description
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.

Register	Parameter	Description
		The following values are valid: • Scale factor = 2 • Scale factor = 1 • Scale factor = 0 • Scale factor = -1

15.8 Discrete inputs details

Input	Parameter	Description
0	IO_SENSOR1_DISCONNECTED	0 = true, 1 = false
1	IO_SENSOR2_DISCONNECTED	0 = true, 1 = false
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.
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/m^2. 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.
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/m^2. 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.
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 to reset the error flag.
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.

Input	Parameter	Description
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.
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.
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 in 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).

15.9 Discrete coils details

Coil	Parameter	Description
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.
18	IO_RESTART_MODBUS	–
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.
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.
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. The default value after power on is ON.
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.

Coil	Parameter	Description
24	IO_CLAMP_IRR	Setting the coil enables irradiance clamping. When irradiance clamping is enabled, the lowest irradiance value is limited to 0. The default value after power on is OFF.

15.10 Requesting serial number

Register	Parameter	Description
41	IO_BATCH_NUMBER	The batch number defines the production year of the smart sensor, 20=2020, 21=2021 etc.
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.

15.11 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 uOperationMode, 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 modus 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_ERRROR, true);
			WaitModbusReply ();
		}
		else if (uStatusFlags != 0)
		{
			SendModbusRequest (0x05, 2, IO_CLEAR_ERRROR, 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);
	}
}
```

Contact Information