Instruction Manual

DustIQ • Soiling monitoring System

Applicable to all models. **Please check regularly for updates.**

Use the section on new firmware and Modbus registers to update the latest "normal" one.

V Mar. 2022-22

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 DustIQ.

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:

1.

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Publication date: **March 2022**

Important changes:

- New firmware with:
  - shorter and easier local dust calibration procedure.
  - comprehensive calibration codes feedback introduced in section 12
  - factory calibration for common desert dust slope to report transmission loss and soiling ratio closer to typical monitoring sites before local calibration is conducted
  - zero-offset correction functionality added
  - possibility to perform in-the-field-reset

May 2021 updates:

- Extra instructions for dealing with transmission loss offsets
- Advice for not yet locally dust calibrated measurements
- Advice to use 24VDC as power supply to get the best measurements
- Extra attention for the right Modbus command "04 Read Input Registers" to get data from the DustIQ.
- Extra Frequently Asked Questions (FAQs)
- Typo correction in section 8.3 (350 should be 50 ‰)

December 2019 updates:

- Added advise not to install the DustIQ horizontally.

October 2019 updates:

- Added Tilt and Panel temperature to Campbell examples

January 2019 updates:

- Full Feature version with tilt sensor, PV panel temperature sensor and daisy-chain capabilities added.
- DustIQ height reduced from 40 to 35mm starting with serial number 180094
- Added status and calibration context flags and stored in Modbus® registers
- Increased minimum irradiation for local dust calibration to 800 W/m^2
- Added remark that 5% transmission loss for local dust calibration equals 50 ‰ in Modbus register 21
- Minor cosmetic updates

Table of contents

Introduction

Reading this entire manual is recommended for a full understanding of this product.

CAUTION

2.

The triangle with exclamation mark is intended to alert the user to the presence of important installation, operating and maintenance instructions in the literature accompanying the instrument.

WARNING Low voltage electrical equipment

This low voltage electrical equipment should only be installed and serviced by authorized personnel, meaning people who have been trained and designated as "authorized" by their employers.

! Useful information for the user

Safety precautions

2.1. Many hazards are associated with installing and maintaining instruments on towers or elevated structures. It is advised to use qualified personnel for installation and maintenance. The client is responsible for following the local safety regulations. The use of appropriate equipment and safety practices is mandatory. Check your company's safety procedure and protective equipment prior to performing any work. If the DustIQ is mounted at a high position, special care must be taken to secure both the person installing it and the instrument from falling during installation.

CAUTION   Handling a breakable instrument

Since the DustIQ weighs 4kg, contains glass and is comparable to a regular PV module it is advised to use the same safety precautions as the ones used for handling and fitting regular PV modules.

While every attempt is made to get the highest degree of safety in our products, the client assumes all risk from injuries resulting from improper installation, use or maintenance of the DustIQ.

2.2.
Waste disposal

2.3. The pictogram showing a waste bin with a cross means that the product is subject to European Union regulations covering segregated waste disposal. This applies both to the product itself and to any accessories marked with the same symbol. Disposal of any such item as unsorted domestic waste is not allowed.

Customer support

In case you need support, please contact:

OTT HydroMet B.V.
2.4. Delftechpark 36, 2628 XH Delft, or
P.O. Box 507, 2600 AM Delft,
The Netherlands
Tel. +31 15 2755 210
solar-support@otthydromet.com
www.kippzonen.com

Warranty and liability

Kipp & Zonen guarantees that the product delivered has been thoroughly tested to ensure that it meets its published specifications. The warranty included in the conditions of delivery is valid only if the product has been installed and used according to the instructions supplied by Kipp & Zonen.

Kipp & Zonen shall in no event be liable for incidental or consequential damages, including without limitation, lost profits, loss of income, loss of business opportunities, loss of use and other related exposures, however incurred, arising from the incorrect use of the product. Modifications made by the user can affect the validity of the CE or FCC declaration.

Product overview

This manual, together with the Smart Explorer manual and instruction sheet, provides information related to the installation, maintenance, calibration, product specifications and applications of the DustIQ soiling monitor.

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

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

The DustIQ soiling measurement instrument

The DustIQ is a unique, high quality instrument designed for measuring the light loss resulting from the soiling of the panel. The measured light loss is an indication for the losses introduced by the soiling of the nearby PV panels too.

3.1. The DustIQ features internal digital signal processing and interfaces optimised for industrial data acquisition and control systems. Kipp & Zonen has developed a smart interface that features RS-485 Modbus® data communication for connection to programmable logic controllers (PLC's), inverters, digital control equipment and digital data loggers.

To achieve the required accuracy, the amount of reflected light is precisely measured and combined with the local dust calibration that has to be performed, the right light loss is calculated.

The DustIQ soiling monitors are normally delivered with a 10m UV resistant cable with an 8 pin plug on the instrument side and wire ends on the other side. Longer 25m and 50m cables are available as well.

Included with the product

3.2. 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 OTT HydroMet representative or e-mail the Kipp & Zonen customer and product support department at: solar-support@otthydromet.com

Contents of part number 0386900 and 0386910: DustIQ panel, 4 mounting clamps with bolts, washers and nuts, instruction sheet, 10 m cable to the host or SCADA system.
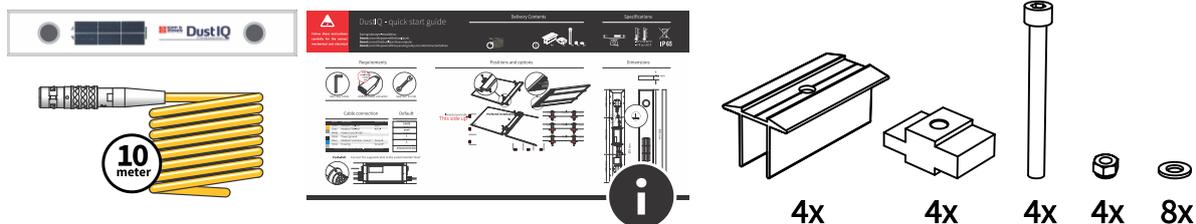
The 0386915 model comes without standard cable and the cable (10, 25, 50, 100m to host or 5,10m daisy-chain) or just the ODU connector must be ordered separately.

3.3. Although all DustIQs are weatherproof and suitable for use in harsh environmental conditions, they have some delicate mechanical parts. Please keep the original packaging for safe transport of the instrument to the measurement site, or for use when returning the instrument for possible repair or recalibration.

Intended use

The DustIQ is meant to measure and report the transmission loss (TL) and soiling ratio (SR) caused by light being blocked and reflected and subsequently not getting through the glass of the panel due to soiling of the panel.

The DustIQ is meant to be mounted next to and in the same plane as the PV panels in the solar park. The instrument is fully waterproof (IP65) and can be cleaned in the same way as the PV panels are cleaned, both wet and dry.

Communication is possible via Modbus® RTU using a RS485 2-wire connection and the power supply needed is 24V and min. 500 mA.

Planning the installation and use of the DustIQ

This chapter describes the best locations to place the DustIQs and how to make the best of the acquired data.

Where to place DustIQ in the PV plant

4.

4.1.

Measuring dust and soiling ratio is a new field of science. There are many opinions about it, but there is no large history of data and experience in measurements. Although the spot measurement of DustIQ is very precise, it is wise to do interpretation and use common sense when extrapolating the measurement value to the whole PV plant, or a part of it, for decision making. The measurement value thus is true, the only question is, whether this value is representative for the PV park.

For giving a good representation of soiling across the PV plant, one should place multiple DustIQs across the plant. In fact, the **IEC61724-1:2021** Standard for PV system performance (Monitoring) prescribes that one should have as many dust-sensors as irradiance sensors. This makes intuitive sense: it follows the same logic as irradiance that also is not constant across a solar plant, and one has to have sufficient measurements to make a valid interpretation. For the number of DustIQs, one can thus follow the own policy for the number of pyranometers. Of course, every additional DustIQ adds up to a better overall measurement. For 1 MW plants, 1 DustIQ placed in the middle could do, whereas for larger plants – say 25 MW- one could imagine the one in the middle, and one near each corner could be a logical choice to understand the soiling pattern across the plant.

Soiling is a different phenomenon than irradiation, and also very site specific. Where you normally expect the same average irradiation value for all pyranometers at a solar plant, this is not necessarily true for DustIQs: if the wind always blows from the east, one could expect more soiling (and thus another cleaning interval policy) at the east side of that solar plant. When wind direction changes over seasons, this pattern could shift during the year. Also, it is known that the very ends of an array, and the bottom row of an array (closest to the ground), typically suffer more from soiling than the rest of the PV modules. Therefore, better not place DustIQs here for cleaning policy, unless your purpose is to learn and study soiling behaviour.

Again, soiling is a new scientific area, especially when applied to solar plants. Kipp & Zonen will build up the application data base along with the users, in order to set standards for best practices. When installing the DustIQs, it makes sense to follow up the instrument readings over a period of weeks, and do visual inspection as to reassure yourself on representative values. DustIQ is designed in such a way, that you can easily dismount it, and put it at another location, where you trust it to give the most representative information for your purpose. DustIQs can be placed at the side, and at the top of PV modules, in the middle of an array or at the sides. Landscape orientation in **not** advised, as soiling is uneven in the vertical direction, influencing the PV module output. Kipp & Zonen has introduced DustIQ-array-fillers, in order to install the DustIQ in the middle of a row and in the middle of an array, without making gaps in the array.

Installation

Please follow the instructions in this section carefully for the mechanical and electrical installation of the DustIQ.

Do not turn on power to the instrument,
Do not connect the instrument to a computer,
Do not turn on power to the operating computer until instructed to do so.

5. Tools required

The tools required to fit the DustIQ to a PV panel are:

5.1.

Allen key 6 mm

Spanner 13 mm
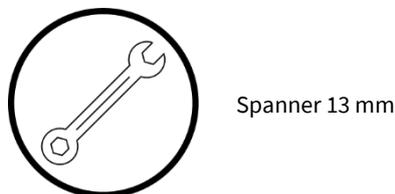
The tools required to change the default DustIQ settings are:

A type of USB-RS485 converter that supports half duplex 2-wire connections and preferably has optical isolation for increased safety and reliability.

5.2.

SmartExplorer software will be available from https://www.kippzonen.com/Product/419/DustIQ-Soiling-Monitoring-System

Pre-installation

If changing the settings from the factory default is needed then it is advised to set the Modbus® address **prior** to visiting the site, otherwise a computer and RS-485 / USB converter may be required during installation. The SmartExplorer software needed for setting the Modbus address and communication parameters is available on the Kipp & Zonen website in the download section. Please perform the following steps before moving DustIQ to the field.

The DustIQ comes with the following **factory defaults**:

5.3.

- Modbus baud rate: 19200
- Parity: even
- Data bits: 8
- Stop bits: 1
- Address: 1
- Local dust profile: Common Desert Dust (CDD)

Connecting the data cable to the DustIQ

Connect the supplied or locally made data cable to the socket labelled **Host**.

First released model (Pn 0386900) which doesn't support daisy-chaining or PV panel temperature sensor:
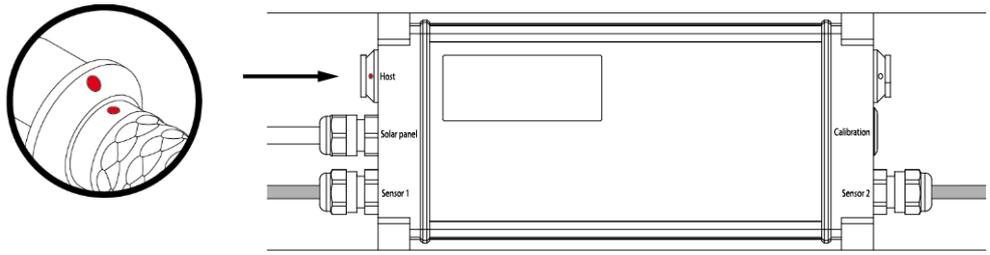
Full feature models (Pn 0386910 and 0386915):
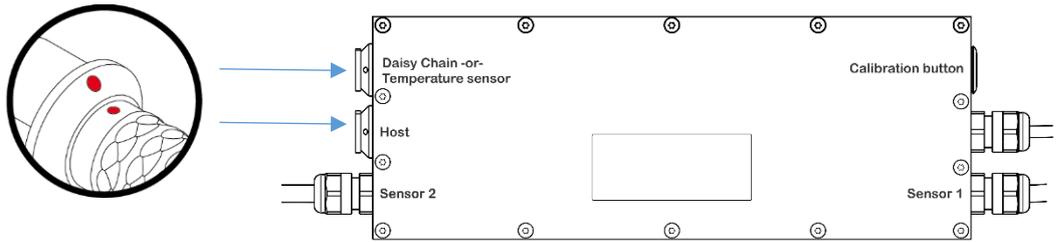
Locate the 8 pin ODU plug correctly in the DustIQ socket, it only fits one way. The red dot on the plug should be opposite of the red dot on the chassis socket. Push it in to secure whilst holding the plug by the end or by the grooved ring.
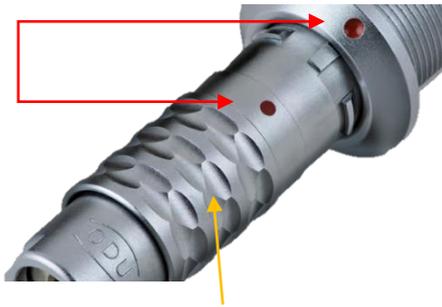
5.4. To unplug, pull the grooved ring back and then pull out the plug.

Connecting the cable to the USB converter and power supply

When using an industry standard USB-RS485 converter the following connections need to be made.
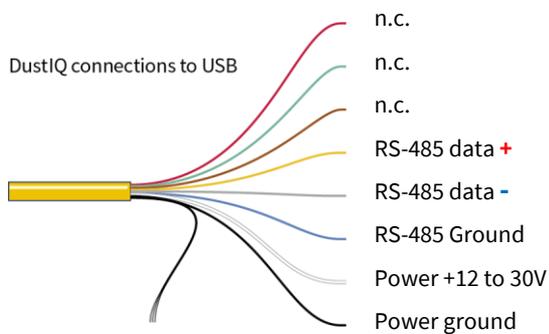
* Switches on the converter should be set for RS-485, 2-wire operation and Echo off

The minimum power supply voltage for the DustIQ 12 VDC. However, for reliable performance it is advised to **use 24 VDC**, especially when longer cables are used or if DustIQs are daisy-chained.

It is advised to protect the output of the power supply with a fast blowing fuse of maximum 500 mA rating.

Typical power consumption of the DustIQ

12 VDC	60 mA LEDs off – 130 mA LEDs on, std duty cycle 5%
24 VDC	40 mA LEDs off – 70 mA LEDs on, std duty cycle 5%

5.5. Connecting the cable to the PMU485 interface box

When using the Kipp & Zonen PMU485 Smart Setup Hub, the following connections must be made:

Green screw terminal, can be unplugged

+12V	White
Power Ground	Black
Data Ground	Blue
D- signal	Grey
D+ signal	Yellow
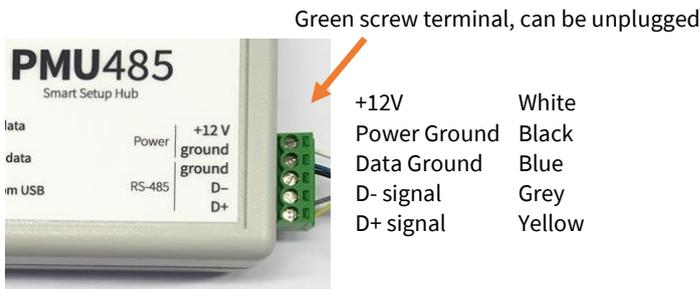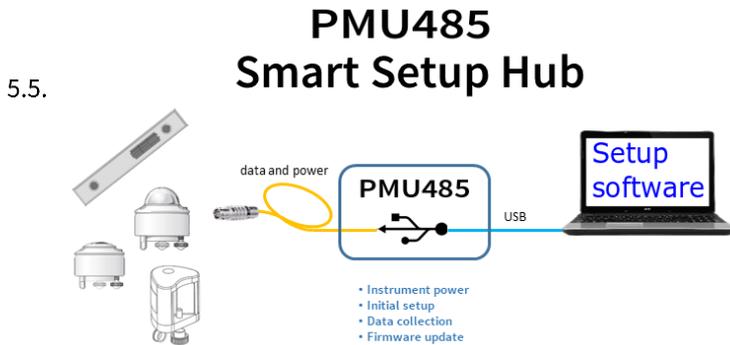
Please see https://www.kippzonen.com/Product/534/PMU485 for more details.

5.6. Changing the settings of the DustIQ

For changing the DustIQ settings, the SmartExplorer software is needed as well as one connected DustIQ.

5.6.1. Finding the COM port

After starting the SmartExplorer software the user needs to select the right COM port on which your USB-RS-485 converter has been installed by the Windows® 7, 8 or 10 operating system.

One way of checking the COM port number is by using the standard Windows Device Manager via Control Panel

First start up

After the first start of the SmartExplorer **V2.0.1.0 (or above)** software, the window below will appear:

5.6.2.
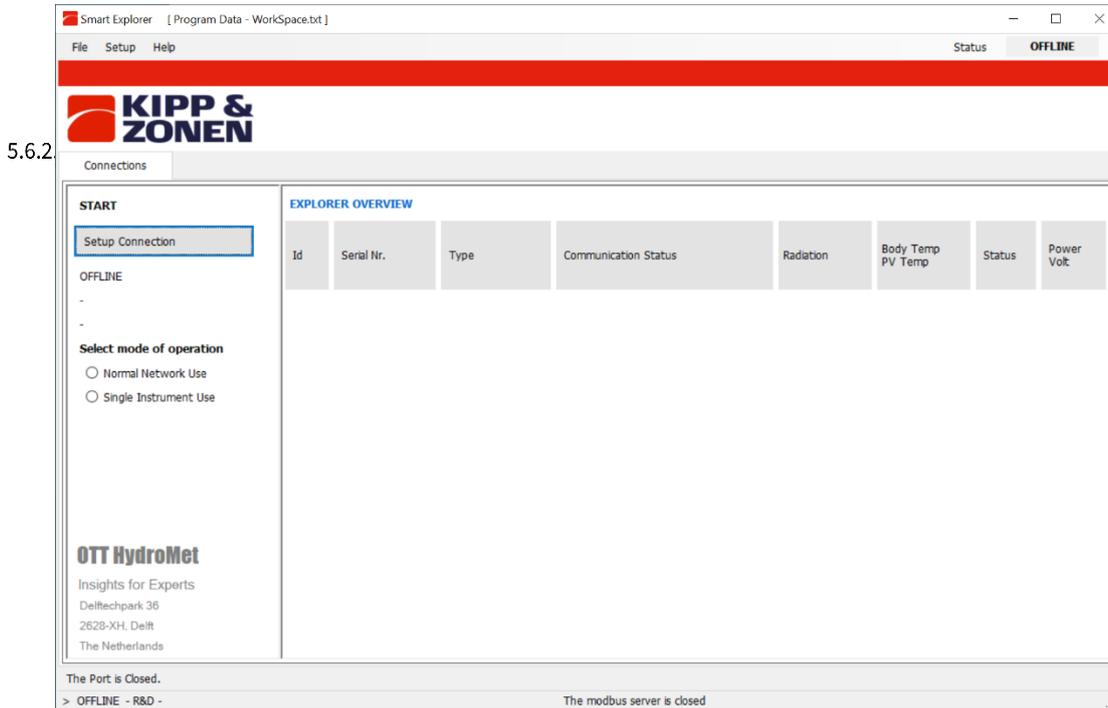
Configuring the settings

5.6.3. In order to connect to the DustIQ: click on Setup Connection
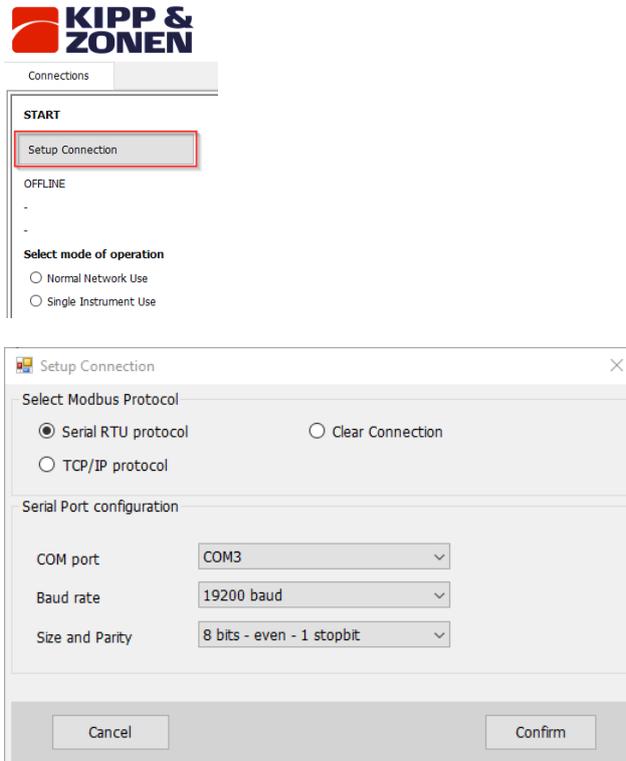
Select Serial RTU protocol for the direct RS485 connection that you're using.
Select the COM port you found in the Windows Device Manager.
Leave the other settings unchanged as these are the factory defaults for all Kipp & Zonen products.

If you have changed the settings and return to the SmartExplorer you have to change the settings to the ones used by your instrument.

Click **Confirm** to save and use the settings.

Main window - connections

Once the SmartExplorer software is able to communicate with the attached DustIQ, the following window will appear:

- The program starts in Normal Network Use, meaning you can have several instruments attached to monitor
- Changing setting is best done with only one instrument attached
- Finding an instrument with unkown communication settings is only possible with one instrument attached
- Allow 5 to 10 minutes for the instrument to stabilise before reading the measurements
- When starting for the first time with a DustIQ straight out of the box, the communication settings that should be used are: 19.200, 8E1

Note: On the initial 0386900 model, Power Volt is not reported correctly and always 3.2V. Later models (0386910 & 15) report the actual supply voltage.

Main Window – Setup

After starting SmartExplorer for the first time it is advised to check and set the following **Setup** selections:

5.6.5.

Main Window – View Device

Clicking on (View Device) tab will bring up the information for the first device. If there are more instruments attached, then use the arrows [←] 01 [→] are to select the right one.

5.6.6.

5.6.7.

Main window – Chart

The chart windows shows a simple rudimentary chart of the selected devices. The scale for the sensor 1 & 2 average soiling ratio is on the left-hand side.

Main window – File Output

To log to the gathered data (from the devices), please use the tab (File Output). Depending on the attached instruments the proper selections are available.
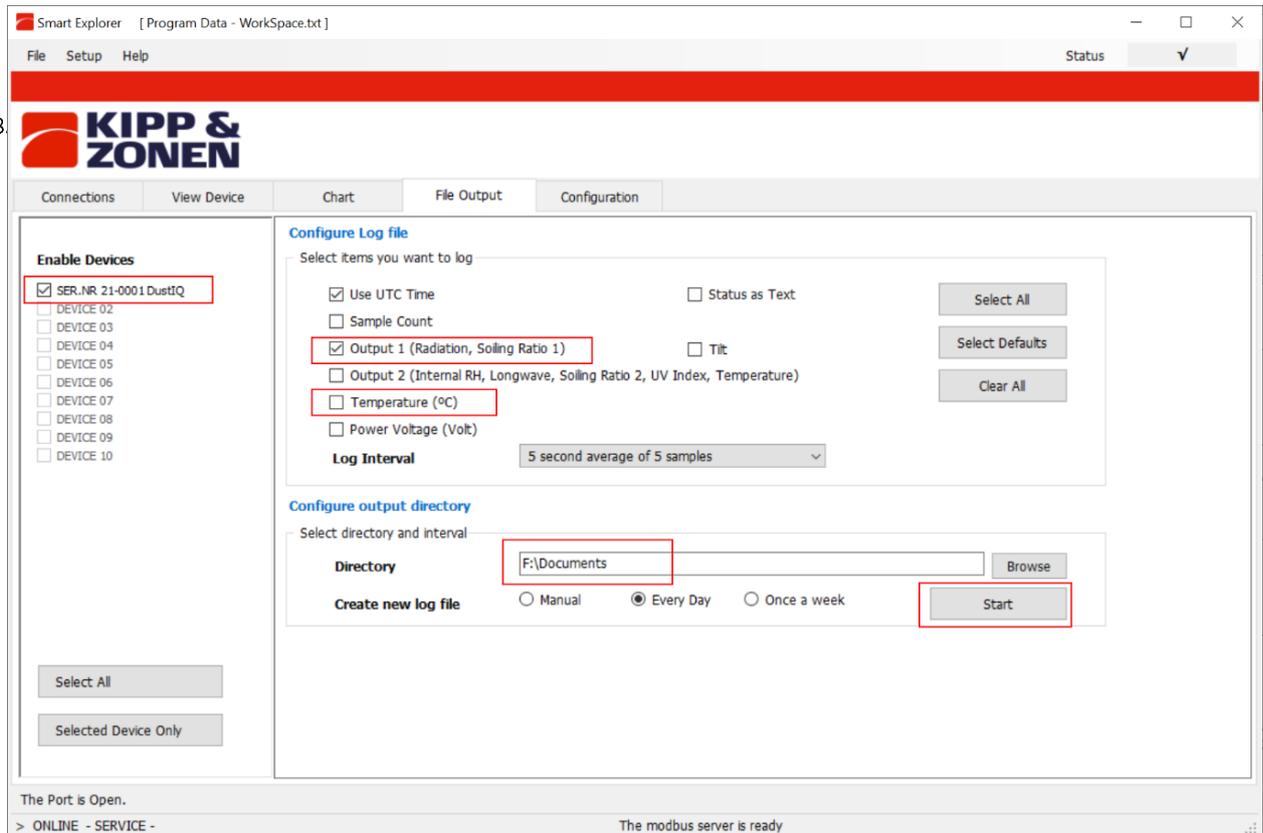
After clicking Start ![Start indicator] will be visible on the right –hand bottom.
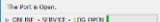
After clicking Stop a CSV file is available in the selected directory ![CSV icon] named LOGyymmdd-hrmm.CSV

5.6.9.

Main window – Configuration

Clicking the (Configuration) tab shows the current communications settings, this is where the DustIQ settings can be changed.
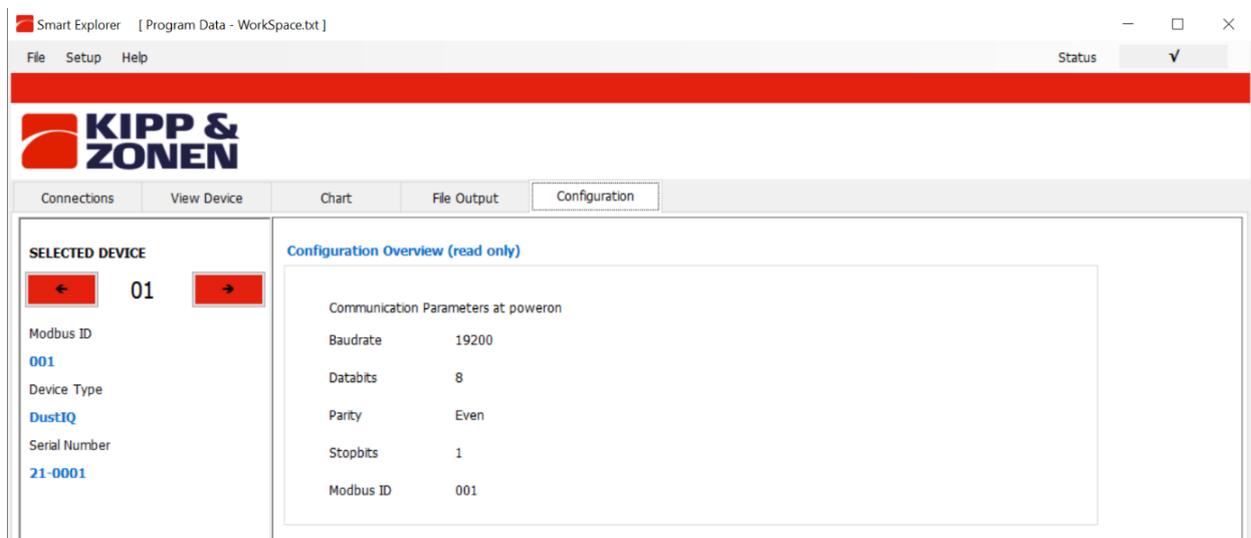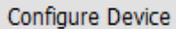
Click on ![Configure Device] and a warning is shown. Read carefully.
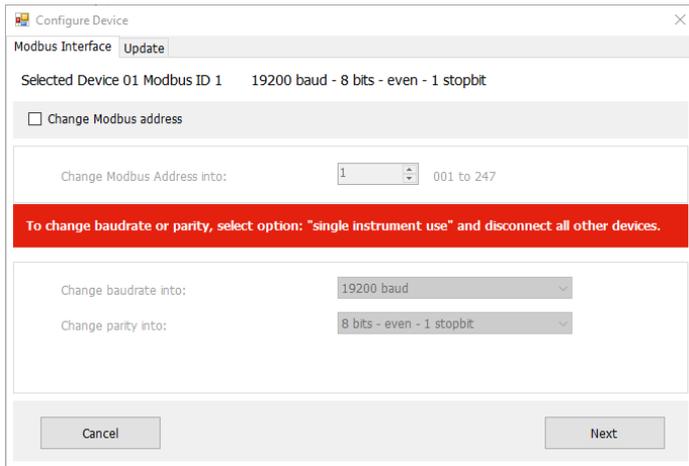
Go back to the first (Connections) tab to change to (Single Instrument Use), when the baud rate or parity needs to be changed too. Modbus address changes work also in (Normal Network Use).

For changing just the Modbus address select (Change Modbus Address) and select the new Modbus address.

followed by Next and Update on the next screen.

Otherwise select the changes needed followed by Next
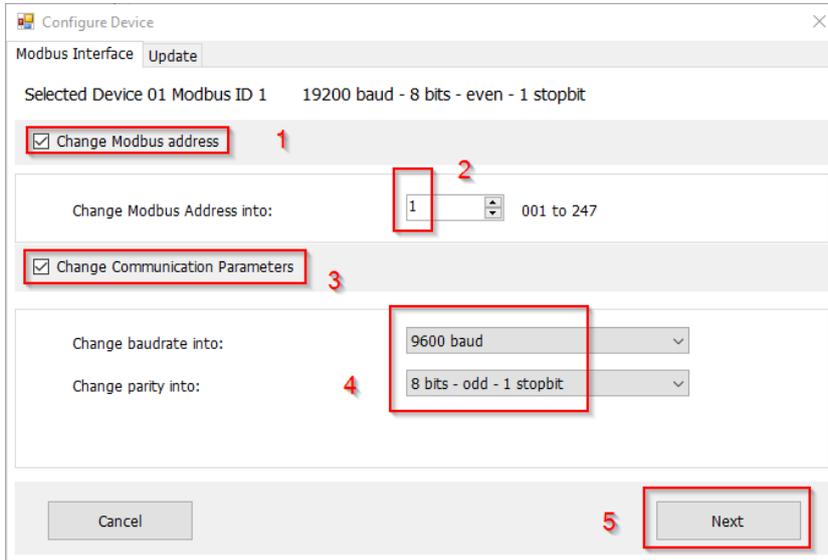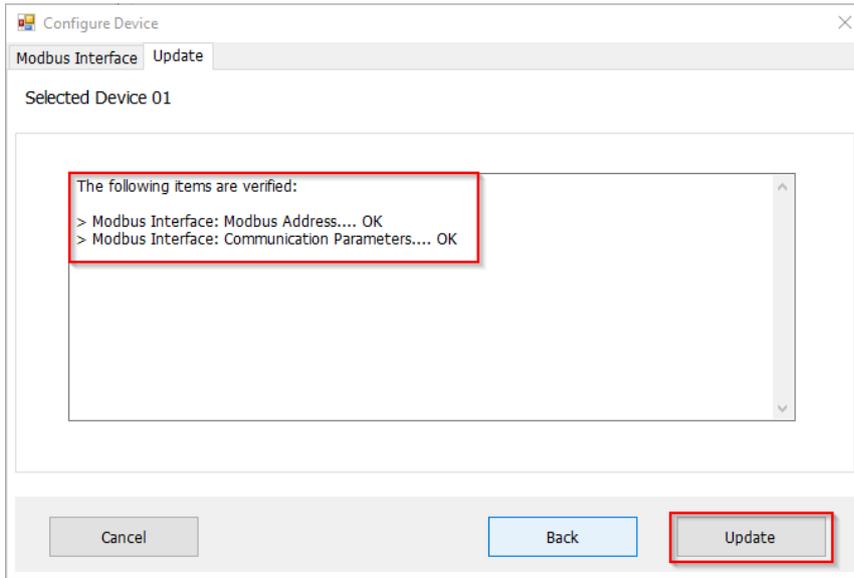
When OK with the changes, click Update.

After updating, the DustIQ will be reset and takes about a minute to be ready again. The communication parameters of the SmartExplorer software have been changed accordingly and a functioning connections tab should appear.
When finished, the program can be closed.

5.6.10 Finding a DustIQ with unknown communication parameters

When unsure of the current DustIQ settings and unable to connect there are two ways to try and find a single connected instrument.

First change to Single Instrument Use in the Connections tab.

When the communicatin parameters are known and properly setup and only the Modbus ID is unknown, a Send Broadcast will find the attached DustIQ and show it.

If no instrument is found then mostlikely also one of the communication parameters is wrong or unknown.

To find a DustIQ, the "Start From Boot" procedure can be used. The procedure includes shortly removing the cable from DustIQ to perform a Power Off – Power On or switch Off and On the power when possible.

Click on Start From Boot and the following window will appear:
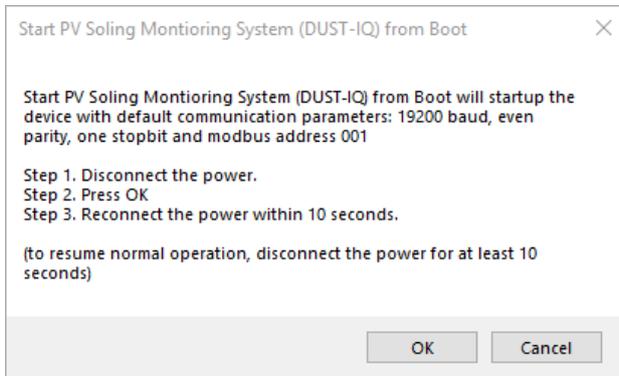
Follow the instructions given and the DustIQ will be found.

EXPLORER OVERVIEW

Id	Serial Nr.	Type	Communication Status
001	16-0009	DustIQ	Device started from boot

After about a minute the (Connections) tab will show reliable measurement results and the communication parameters setup of the DustIQ can be seen and changed on the (Configuration) tab.
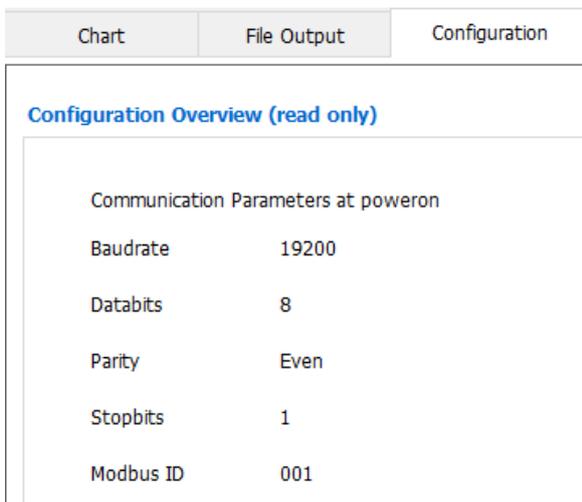
Mounting the DustIQ outside

The DustIQ – quick start guide contains all the outline information necessary for the correct installation of the DustIQ.

The DustIQ is provided with 4 clamps for installation alongside a PV panel. Sensor 1 (as indicated below) should be the lower sensor when installed in portrait orientation (vertically) alongside the PV modules.

5.7. When mounted in between PV panels the 4 supplied clamps will be enough and these can take care of a possible + or - 5mm difference in height.

Version 1 of the DustIQ has a height of 40 mm. Later models with serial number 180094 and higher have a height of 35 mm.
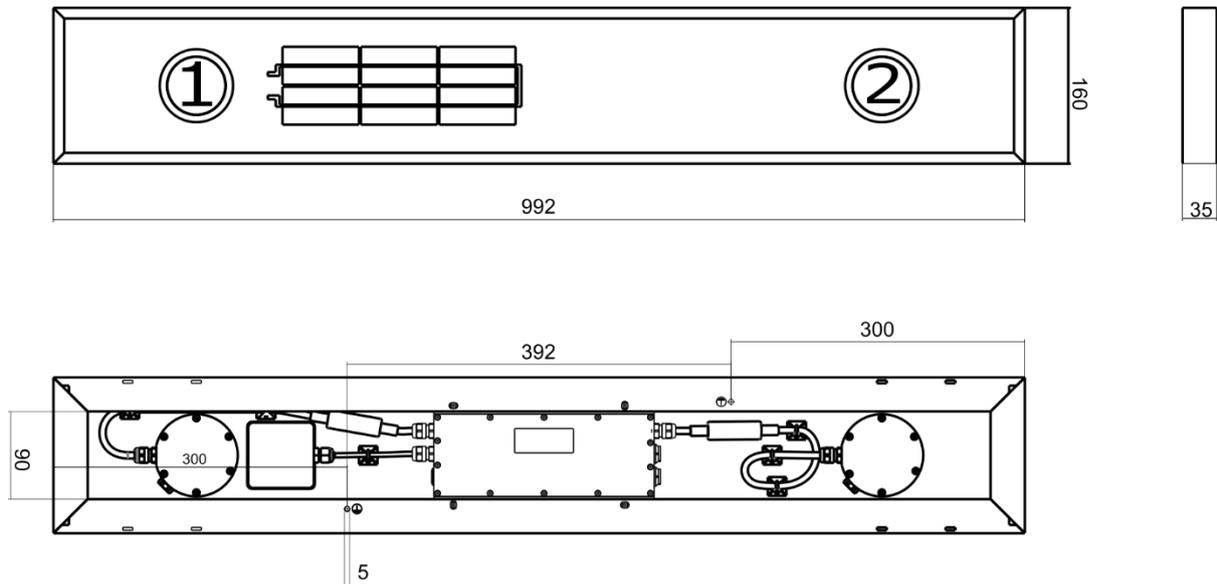
DustIQ weight is 4 kg.

Sensor 1 (the one closest to the PV cell) is the bottom sensor for portrait orientation (vertically) installation.

5.8.

DustIQ physical installation

The DustIQ comes with 4 clamps for mounting in between PV panels.

For other setups, a locally made supporting structure is needed.

Prefered installation
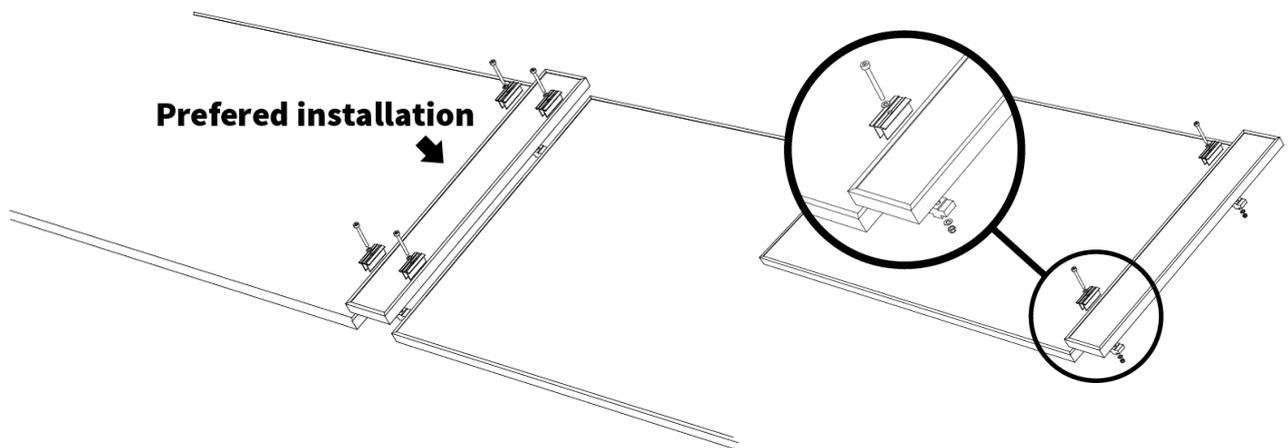
Use of the clamps for installation

Several scenario's with different PV panel and DustIQ heights can be dealt with using the supplied clamps.

Rotating the bottom clamp around the Y-axis deals with height differences of plus or minus 5mm. (top drawings).

A 35mm DustIQ can be clamped in between PV modules of 30, 35 and 40mm.

5.9.

Rotating the clamps around the x-axis works for several heights panel and DustIQ.
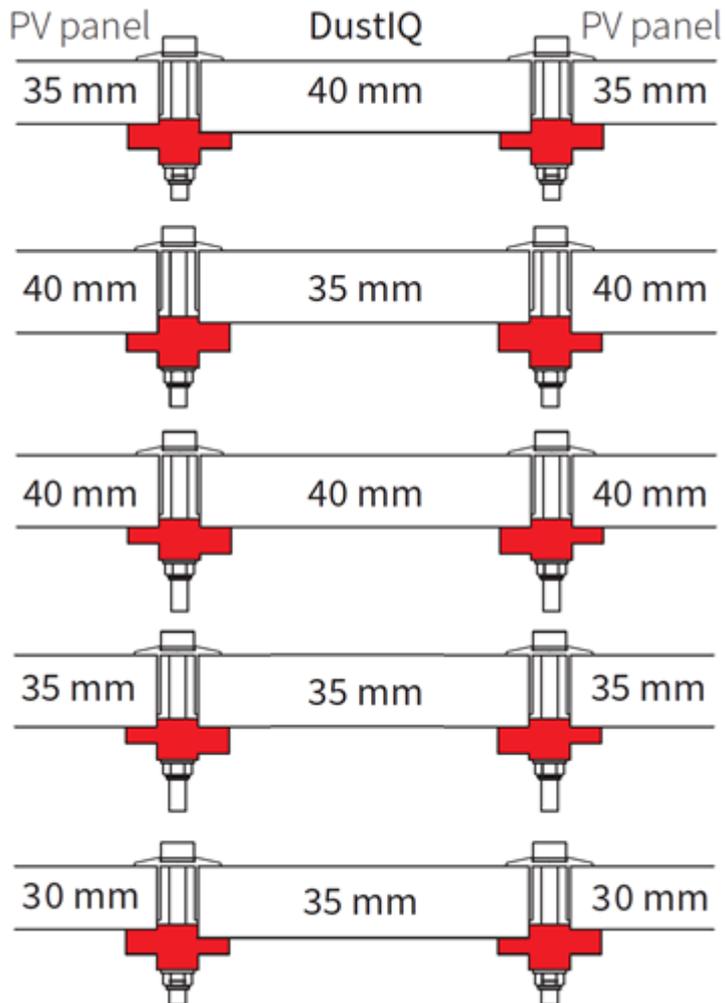
As of serial number 180094 the height of the DustIQ changed from 40mm to a lower 35mm.

Suggested clamping distances:

400 - 800mm
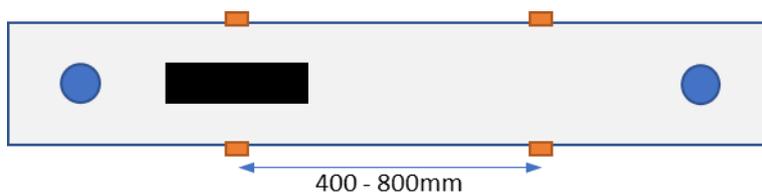
For **testing purposes in areas with limited chance of winds stronger than 6 Beaufort** it is possible to use the supplied clamps and install the DustIQ without supporting structure on a spot where two PV panels meet.
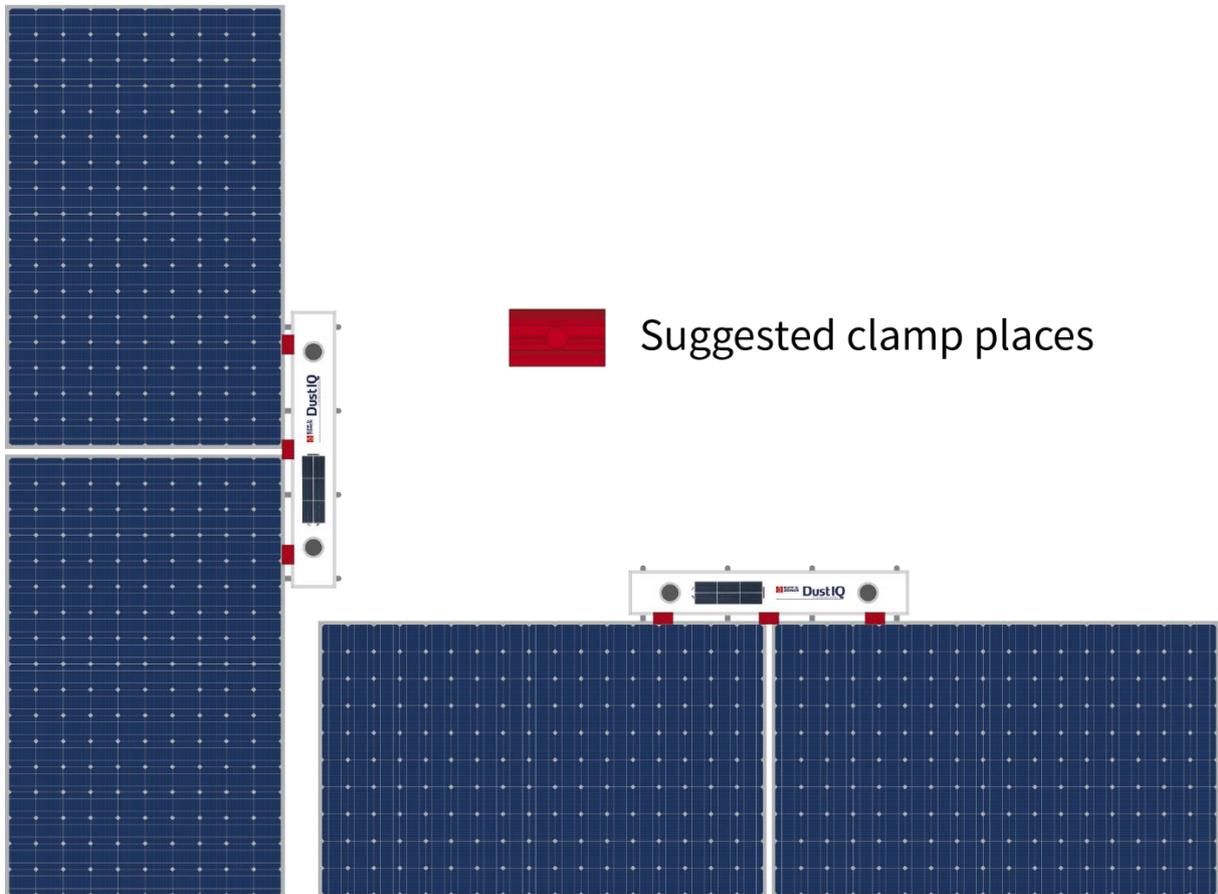
For other setups, a locally made supporting structure is needed.

Landscape orientation (horizontal orientation) installation is not advised, as soiling often is uneven in the vertical direction (further details were mentioned in section 4.1).

Examples of securely installed DustIQs:

If the DustIQ is installed on a support structure it is advised to use the same end-clamps as you would for 35mm heigh PV modules. The supplied clamps are not meant to be used as an end-clamp.

Some widely and locally available examples:

5.10. Fitting the host connector and cable outside:

Most DustIQs are supplied with a 10m high quality yellow cable fixed to an 8 pin waterproof connector on one end and 8 wires and a shield covered with a black sleeve on the other end. Longer cables are available as an option.

The wire ends are to be connected to the data logger or SCADA system directly or to a junction box which in turn is connected to the host.

The colour code of the wires and the connector pin numbers are shown below and on the instruction sheet.

DustIQ connections		
Wire	Function	Connect to
1 Red	None	
3 Green	None	
6 Brown	None	
4 Yellow	Modbus® RS-485 B+	B/B'/ + on host or USB converter
5 Grey	Modbus® RS-485 A–	A/A'/ – on host or USB converter
2 Blue	Modbus® common / Ground	
7 White	Power +12 to 30 VDC	
Black	Power ground / RS-485 Common	
Shield	Housing	Ground

Front view
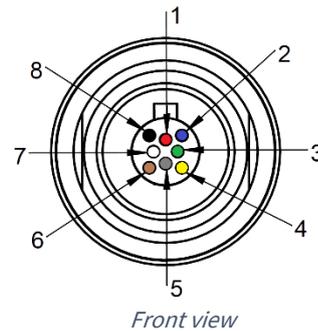
Note   First connect all wires in your junction box, SCADA system or data logger **before** plugging into the DustIQ.

The shield of the cable is connected to the aluminium DustIQ housing through the connector body. Preferably, secure the DustIQ with a good connection to ground (e.g. by using a lightning conductor) and do not connect the cable shield at the junction box, SCADA system or data logger.

If there is no good ground connection at the DustIQ, the shield at the cable end should be connected to ground at the host or junction box.

Note   Long cables may be used, but the baud rate of the RS-485 digital connection may affect the maximum length. Baud rate options are: 2400 , 4800 , 9600, 19200 (default), 38400

Locate the plug correctly in the DustIQ socket labelled Host, it only fits one way, and push it in. Locking is done automatically.
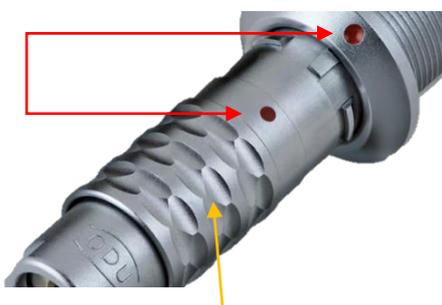
To unplug, pull the grooved ring back and then pull out the plug.

It is advised to protect the output of the power supply with a fast blowing fuse of maximum 500 mA rating.

❗ The cable should be arranged with a curve below the instrument so that water drips off, rather than running along the cable up to the connector.

If the cable needs to be extended it is advised to use high quality UV resistant CAT5 cable.

❗ It is also advised to place proper surge protection on the power and data lines in your junction box or near your data logger.

5.11 Fitting the daisy-chain cable

❗ Below instructions are valid for DustIQs with Pn 0386910 or Pn 0386915.The initial model DustIQ Pn 0386900 does **not** have this capability.

When installing several DustIQs in relative proximity they can be daisy-chained up to **3 instruments** in total and have only one data and power cable to the host, data logger or junction box.

Each unit needs to have a unique Modbus address setup before installation.

If this DustIQ is the only one or the last in a daisy-chain of max. 3 instruments one can fit the supplied PV panel temperature sensor.

The plug of the daisy-chain cable fits in the port labelled Daisy-chain / Temp sensor and leads to the Host port on the DustIQ next in line.

Both plugs of the daisy-chain cable are identical.

5.12. Installing the PV panel temperature sensor

❗ Below instructions are valid for DustIQs with Pn 0386910 or Pn 0386915. The initial model DustIQ Pn 0386900 does **not** have this capability.

When daisy-chain port isn't used to connect a second instrument, then it can be used to connect the supplied PV panel temperature sensor. The sensor comes with a 2.95m long cable and can be fitted on a nearby PV panel that represents the average PV panel temperature the best.

Install the PV panel temperature sensor by the following steps:

a) From the DustIQ, remove the black dust cap of the daisy-chain connector
b) Insert the plug in the connector of the DustIQ
c) Clean the surfaces of the locations for the cable supports and for the PV panel temperature sensor at the back of the PV panel
d) The best location for the temperature sensor is the centre of the PV panel
e) Stick the temperature sensor to the cleaned surface at back of the PV panel
f) Place with care as the temperature sensor is hard, if not impossible to remove
g) Stick the cable tie mounts to the cleaned surfaces at the back of the PV panel
h) Secure the cable to the cable supports by using tie wraps

Mounting the PV panel temperature sensor
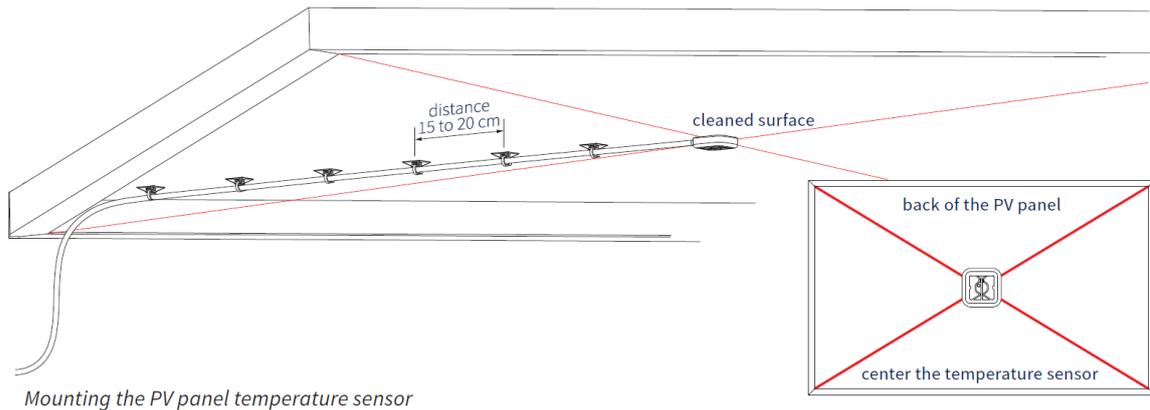
❗ Double check the intended temperature sensor position before removing the backing of the double sided tape, as the sensor will stick extremely well and is very hard if not impossible to remove.

Connection to a RS-485 network

5.13. The DustIQ must be connected as a server to a 2-wire RS-485 network as shown below.
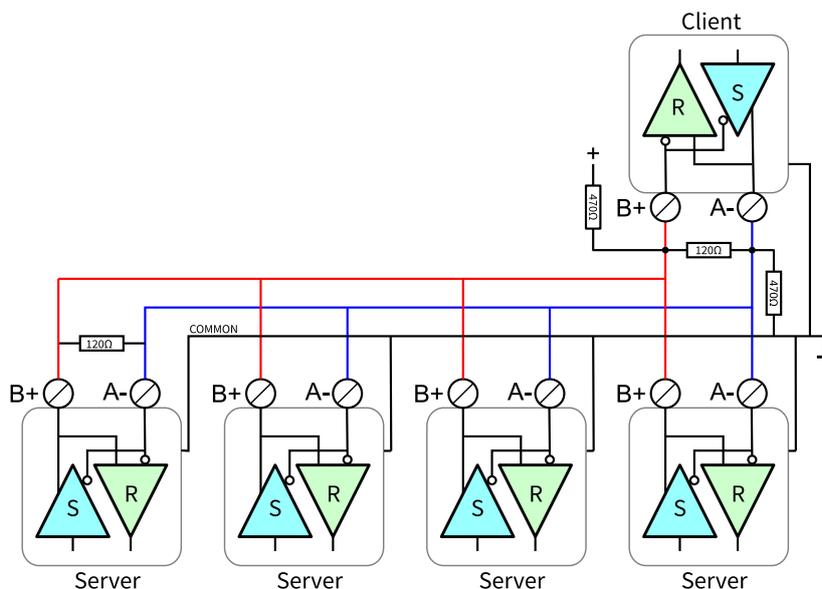
The servers may be a DustIQ, an SMP pyranometer or other 2-wire Modbus RTU device. If this instrument is the last device on the network a line terminator (LT), consisting of a 120 Ω or 150 Ω resistor, must be connected between terminals A/A /Data▬ and B/B /Data+ right at the last device. It is also required to have the pull up and pull down resistors close to or in the client as shown. The value of these resistors must be between 470 Ω and 850 Ω.

There are many resources available on the internet on RS-485 connections and an example is: https://electrical-engineering-portal.com/correct-cabling-modbus-rs485

5.14. ❗ It is also advised to place proper surge protection on the power and data lines in your junction box or near your data logger.

Electrical details

❗ The minimum power supply voltage for the DustIQ is 12 VDC. However, for optimal performance it is advised to **use 24 VDC** when longer cables are used.

It is advised to protect the output of the power supply with a fast blowing fuse of 500 mA rating for one DustIQ. When daisy-chaining a bigger fuse is needed.

Typical power consumption of the DustIQ

12 VDC	60 mA LEDs off – 130 mA LEDs on, std duty cycle 5%
24 VDC	40 mA LEDs off – 70 mA LEDs on, std duty cycle 5%

Maximum average power consumption over a minute is 1000 mW at 24V and 800 mW at 12V.
Maximum input current is 150 mA at 12V voltage.
Maximum inrush current is 10A for 50µs.

The DustIQ needs a good, stable power supply of 12-30V, 300mA peak and 200mA sustained. For resilience a 500mA power supply is advised. Preferably class II to IEC/EN 60536. A power supply with genuine and traceable CE, FCC, VDE, TUV or equivalent certification.

24VDC is advised for optimal performance.

Some of the brands applicable: Traco, Omron, Mean Well, Cosel and others.

5.15. EMC and Surge protection details

The DustIQ passes the most-stringent tests for Immunity & Emissions it conforms to all the EMC requirements for Commercial, Residential, Light Industrial, Industrial, Scientific & Medical Equipment, as well as Measurement Control & Laboratory Use.
In order to pass the above mentioned standards the DustIQ offers the following internal electronics protection:

Power input with 2-stage protection   **RS-485 with 3-stage data line protection**
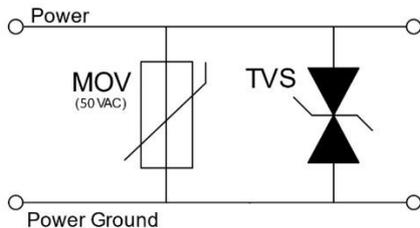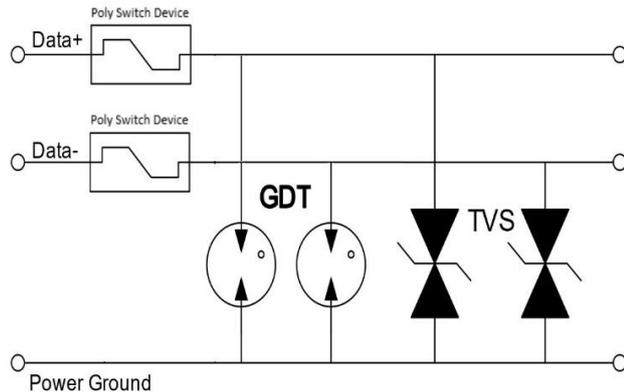
Power Supply Surge Protection VDC+ and VDC-	TVS Diode and Metal Oxide Varistor
Power supply surge standoff voltage	56 V
Power supply surge protection peak pulse current	800 A
Power reverse protection	Included
RS485 Surge Protection Data+/Data- to signal ground	Gas Discharge Tube, TVS Diode and Poly Switch Device
Gas Discharge Tube standoff voltage	90 V
Surge protection peak pulse current, 8x20µs 300 Hits (150 Hits Each Polarity)	100 A
Poly Switch Device	200 mA , 400 V
TVS diode standoff voltage	43 V

The function of the Poly Switch Device is to switch off the entire RS485 when a surge pulse is applied on the input
Each line (Data+ and Data-) has its own Poly Switch Device
A small resistor of 10 Ohm is placed in-line with the Poly Switch Device protection

Note : For external surge protection the DustIQ is seen as "a varistor".

Note : For proper surge protection it is vital to use the double wire connection for Power Ground.

Operation and measurement

The DustIQ only requires a suitable source of power to operate and make measurements. However, it is necessary to connect it to some sort of readout or data storage device in order to save the measurements, there is no internal data memory.

6. Data collection

An optimal setting for the data collection interval is to sample every 1-15 minutes and later post-process the data and remove data points influenced by e.g. rain or dew.

For setting up the combination of the DustIQ and data storage please refer to the manual of your data collection device.
6.1. The data that can be collected is described in appendix B.

Housing

The DustIQ housing accommodates all the key parts of a DustIQ. The anodized aluminium parts are lightweight and give high mechanical and thermal stability to the instrument. The glass panel is equivalent to a real PV panel. The DustIQ has
6.2. an ingress protection rating of 65 (IP65) which means it is dust proof against harmful dust and can withstand waterjets from any direction.

Taring and Local Dust Calibration procedures
7.

After the mechanical installation of the device, if the device is new (out of the box), It is strongly recommended to perform taring then calibration procedures for optimal performance. The precise steps for both procedures are supplied with the device. In addition, the last update of the both procedures are always downloadable from www.kippzonen.com/downloads.

7.1.
The advantage of a local dust profile

The latest firmware 2.xxxx DustIQs leave the factory calibrated for "Common Desert Dust" (CDD). This dust type is the average of received customer feedback of various high soiling location around the world.

Still it is unlikely that the local dust composition matches this CDD exactly and it is therefore advised to train each DustIQ for the local dust composition. Or train one in a PV plant and post-process the measurements of the other DustIQ.

7.2. For the local dust calibration the DustIQ has a build-in PV cell. This PV cell allows the DustIQ to quantify the effect of the
7.2.1. local soiling on an actual PV cell and subsequently correlate this to the DustIQ measurements of reflected light as produced by the soiling.

Post-processing of old DustIQ data after local dust calibration

Introduction
7.2.2.

For some DustIQ users there is a need to know the Transmission Loss (TL) before they were able perform the local dust calibration. The local dust calibration changes the dust slope and therefore the old data is only considered qualitative data, not quantitative. In order to gain quantitative insight in the data before the field calibration, it is possible to do a post-processing correction. In this section the method is described.

Method

The following method applies for both dust slopes. Once finished with 1st dust slope, it should be applied to the 2nd dust slope:

The old recorded TL can be post-processed to the new ones by calculating TL_{new} for each data point

Step 1:
Retrieve the old sensitivity S_{old} from the DustIQ or calibration certificate:

The **old** sensitivity must be obtained by reading and writing down the Modbus register 36 (Sensitivity Sensor 1) **before** local dust calibration. It's a Long integer value in the range of 30-300 and fully instrument specific.
(*for DustIQs that have **not** been upgraded and **never** had a successful local dust calibration this is also the value Sensitivity_Sensor 1 on the calibration sheet*)

Step 2:
Retrieve the new sensitivity S_{new} from the DustIQ

The **new** sensitivity can be obtained by reading Modbus register 36 (Sensitivity Sensor 1) **after** the local dust calibration. Only the correction factor from Old to New can be used. The values themselves are fully instrument specific.

After obtaining the S_{old} and S_{new} the old TL can be post-processed using formula 1.

This is also true for data obtained with other DustIQs on the same PV plant that the user can't or doesn't want to locally calibrate.

$$TL_{new} = \frac{S_{new}}{S_{old}} TL_{old} \qquad\qquad (1)$$

where TL_{new} is the new corrected transmission loss, TL_{old} is the old uncorrected transmission loss, S_{old} is the old Sensitivity before local dust calibration and S_{new} is the new Sensitivity after local dust calibration.

The new post-processed Soiling Ratio (SR_{new}) can also be calculated from the old Soiling Ratio (SR_{old}) using formula 2.

$$SR_{new} = 100 - \frac{S_{new}}{S_{old}} (100 - SR_{old}) \qquad (2)$$

Table 1 Simple post-processing work flow

1	Retrieve and record Modbus register 36 **before** calibration	S_{OLD}
2	Retrieve and record Modbus register 36 **after** calibration	S_{NEW}
3	Calculate correction factor	CF = S_{NEW} / S_{OLD}
4	Calculate TL_{NEW}	TL_{NEW} = TL_{OLD} * CF
	or	
5	Calculate SR_{NEW}	SR_{NEW} = 100 – CF * (100 – SR_{OLD})

7.3.

Making of a local dust profile

7.4. For making a local dust profile please refer to the latest instruction sheet at
https://www.kippzonen.com/Product/419/DustIQ-Soiling-Monitoring-System

8. ## Reset to factory dust calibration

Press the DustIQ calibration button for a minimum of 15 seconds. Then the sensors will flash every 2 seconds for about 15 seconds. The calibration button will flash every 1 second also for 15 seconds long.
The dust slope registers 36 and 38 will be reset to factory default as mentioned on the calibration certificate that came with the DustIQ.

Maintenance and re-calibration

The DustIQ is simple to maintain and doesn't require any special tools or training. There are no service items requiring scheduled replacement.

Yearly maintenance

Check all the electrical connections.
Check cables for damage caused by accident or by rodents.
Check the instrument mounting.

Cleaning

8.1. As the DustIQ has been built using actual PV panel glass it is meant to withstand the cleaning cycles PV panels, as found in commercial solar parks, can withstand. Care must be taken not to scratch the panel's surface or use abrasive or etching compounds.

8.2.　　Calibration

A DustIQ gives an output that is proportional to the light loss caused by the panel soiling. It uses internal correction for any unforeseen parameter drift and therefor needs no calibration apart from the local dust calibration to train the DustIQ for the locally deposited dust.

8.3.

Specifications

OTT HydroMet reserves the right to make changes to specifications and other product documentation without prior notice.

Optical and electrical

9.

9.1.

Transmission loss (TL) range Percentage of sunlight that is blocked or scattered in such a way that it does not reach the actual solar cells.	0 – 50 %
Soiling Ratio (SR) range	100 – 50 % (SR = 100 –TL)
Transmission loss measurement accuracy :	± 1 % and ± 1/10 of reading *
Tilt X and Y-axis **	-180 to 180° ±1°
PV panel temperature measurement **	-20 to +100 °C ±1°C
Ambient working temperature	-20 to +60 ˚C
Storage temperature	-20 to +80 ˚C
IP Class	IP65
Communication	Modbus® over 2-wire RS485
Maximum voltages on data lines	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. Higher voltages will be shorted to ground, disrupting data communication. It is therefore that we advise to have proper grounding and use Surge Protection Devices (SPD)
Connection	One 8 pin ODU connector
Power	12 to 30 VDC, 70 to 200mA **a 24 V, minimum 500 mA power supply is advised**
Power consumption	< 2.5 Watt
Daisy-chain capability **	Three instruments max. in one chain. Only the last device can have the PV panel temperature sensor attached. Supply voltage needs to be 16V minimum for daisy-chaining.
In rush current	Maximum inrush current is 10A for 50µs.
Glass type	standard PV glass

* After well performed local dust calibration
** Is for Pn 0386910 and 0386915 only

It is advised to protect the output of the used power supply with a fast blowing fuse of maximum 500 mA rating.

9.2.

IP**6**5 Protection against Dust	IP6**5** Protection against Water
First digit	Second digit
0 – no protection	0 – no protection
1 – protection against large foreign bodies	1 – protection against dripping water
2 - protection against medium foreign bodies	2 – protection against inclined dripping water
3 - protection against small foreign bodies	3 – protection against spray water
4 - protection against foreign bodies	4 – protection against splash water
5 – Dust protected	**5 – protection against water jets**
6 – Dust tight	6 – protection against powerful water jets
	7 – protection against immersion
	8 - protection against submersion

Dimensions and weight

Dimensions packed	120 x 20 x 8 cm
Dimensions unpacked	99 x 16 x 3.5 cm
Weight packed with 10m cable	6 kg
Weight unpacked	DustIQ unit: 4 kg; Mounting clamps: 600 g; 10 m cable: 400 g

Trouble shooting

There are no user-serviceable parts within the DustIQ and it must not be opened or taken apart without the agreement and instruction of OTT HydroMet and only by qualified personnel.

Output signal not present or incorrect

10.

The following contains a procedure for checking the instrument in case it appears that it does not function correctly:

1. Check the DustIQ cable wires are properly connected to the readout equipment.
2. Check the power supply (24 VDC recommended).

10.1
3. Check that the instrument has a unique Modbus® address and the right communication parameters.
4. Check the instrument location.
5. Check the glass surface, it should unbroken and unscratched.

Any malfunction or visible damage should be reported to your OTT HydroMet representative, who will suggest the appropriate action.

Appendix A

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.

1.

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 DustIQ makes a difference between a holding register and an input register. **Only use 04 Read Input Registers** to get data from the DustIQ.

2.

DustIQ release 3.03 data model

The following section describes the data registers belonging to data model 3.03 as released for all models as a firmware upgrade and installed in the factory. Data model 3.03 belongs to firmware version 22000 and higher.

The DustIQ makes a difference between a holding register and an input register. Only use 04 Read Input Registers to get data from the DustIQ.

2.1.

Overview of the Modbus® registers

These registers are read-only and 16 bits wide unless otherwise specified.

The base of the input register block is set to 1 (MODBUS PLC address [base 1]), or 0 (MODBUS Protocol Address [base 0]) and occupies max. 100 registers (0-99, [base 0]).

The address field in the table below is the Protocol address with base 0 and not the PLC Address with base 1.

COMMON DATA BLOCK DUSTIQ					
PARAMETER	ADDRESS	R/W	SZ	LEVEL	DESCRIPTION
IR_DEVICE_TYPE	0	R	U	All	Device type of the DUST-IQ sensor 800 for DustIQ
IR_DATAMODEL_VERSION	1	R	U	All	Version of the data model (=303 for current version)
IR_SOFTWARE_VERSION	2	R	U	All	Software version of the firmware (22000 or higher)
IR_BATCH_NUMBER	3	R	U	All	Production year in yy format
IR_SERIAL_NUMBER	4	R	U	All	Production serial number for the above mentioned year from 0000 to 9999
IR_HARDWARE_VERSION	5	R	U	All	Hardware version (= 5 for current hardware)
IR_CALIBRATION_YEAR	6	R	U	All	Factory calibration year 2000 to 2099
IR_CALIBRATION_MONTH	7	R	U	All	Factory calibration month 1 to 12
IR_CALIBRATION_DAY	8	R	U	All	Factory calibration day 1 to 31
RESERVED	9-19				Reserved for future expansion

REAL-TIME DATA BLOCK, SOILING SENSOR 1 (SENSOR CLOSEST TO THE INTEGRATED PV CELL)					
PARAMETER	ADDRESS	R/W	SZ	LEVEL	DESCRIPTION
IR_SOILING_RATIO_SENSOR1	20	R	U	N,S	Soiling ratio SENSOR 1 in ‰ (per mille), divide by 10 for % Valid values are 1010 to 500 ‰ 9999 when not valid
IR_TR_LOSS_SENSOR1	21	R	S	N,S	Transmission Loss SENSOR 1 ‰ (per mille), divide by 10 for % Valid values are −10 to +500 ‰ 9999 when not valid
RESERVED	22-23				Reserved for future expansion

REAL-TIME DATA BLOCK. SOILING SENSOR 2					
PARAMETER	ADDRESS	R/W	SZ	LEVEL	DESCRIPTION

REAL-TIME DATA BLOCK. SOILING SENSOR 2					
IR_SOILING_RATIO_SENSOR2	24	R	U	N,S	Soiling ratio SENSOR 2 in ‰ (per mille) , divide by 10 for % Valid values are 1010 to 500 ‰ 9999 when not valid
IR_TR_LOSS_SENSOR2	25	R	S	N,S	Transmission Loss SENSOR 2 ‰ (per mille), divide by 10 for % Valid values are −10 to +500 ‰ 9999 when not valid
IR_CALIBRATION_STATUS_BEFORE	26	R	U	N,S	Informs on **readiness** of DustIQ for local dust calibration
IR_CALIBRATION_STATUS_AFTER	27	R	U	N,S	Informs on **completion** of DustIQ local dust calibration

TILT SENSOR BLOCK					
PARAMETER	ADDRES	R/W	SZ	LEVEL	DESCRIPTION
IR_TILT_X_DIRECTION	28	R	S	All	Tilt X direction (long axis) -179.9 to +180.0 in steps of 0.1 degree
IR_TILT_Y_DIRECTION	29	R	S	All	Tilt Y direction (short axis) -179.9 to +180.0 in steps of 0.1 degree
RESERVED	30				Reserved for future expansion

TEMPERATURE SENSOR BLOCK					
PARAMETER	ADDRES	R/W	SZ	LEVEL	DESCRIPTION
IR_BACKPANEL_TEMP	31	R	U	All	PV panel temperature in 0.1 Kelvin. Value -2732 and divided by 10 is Celsius

DEVICE COMMON BLOCK					
PARAMETER	ADDRES	R/W	SZ	LEVEL	DESCRIPTION
IR_DEVICE_VOLTAGE	32	R	U	All	Device voltage in mV
IR_OPERATIONAL_MODE	33	R	U	All	Operational mode: normal =1, (service =2 , calibration = 3)
IR_STATUS_FLAGS	34	R	U	All	Device Status flags (0 = status OK)
RESERVED	35	R	U	All	reserved
IR_D_SLOPE1	36	R	U	All	Dust slope of bottom sensor 1. Will change after local dust calibration. The factory value is mentioned on the calibration sheet as Sensitivity sensor 1.
RESERVED	37				Reserved for future expansion
IR_D_SLOPE2	38	R	U	All	Dust slope of top sensor 2. Will change after local dust calibration. The factory value is mentioned on the calibration sheet as Sensitivity sensor 2
RESERVED	39				Reserved for future expansion

The following modus registers are used for calibration, identification and error handling. These registers can be asked for in order to facilitate remote problem solving.

DEVICE INTERNAL BLOCK					
PARAMETER	ADDRESS	R/W	SZ	LEVEL	DESCRIPTION
INTERNAL_VALUES_FOR_ERROR_ HANDLING	40 - 99	R			For identification and error handling

Legend: Parameter   Unique name of the register
         Address   Modbus PLC address
                    note: the Modbus PLC address is the Modbus Protocol Address + 1
         R/W   R= Read only / write ignore or R/W = read-write
         SZ   Data type and size; the following data types are used:
              U   16 bit unsigned integer
              S   16 bit signed integer
         Level   The following levels are used:
              N   Available in the normal operational mode
              S   Available in service/configuration level
              All   Available in all modes except the terminal mode.
         Description   Description of the parameter

S   light grey background means new or changed value from original communication.

Soiling ratio % = 100 – Transmission Loss %

All soiling and transmission loss values are stored in 1/10 of a % also known as ‰.

All measurement values need to be divided by ten. E.g. the device voltage reported as 156 at address 32 represents a voltage of 15.6 V and a soiling ratio reported as 985 represents 98.5%

Communication parameters are user selectable from the following range using the SmartExplorer software

DEVICE COMMUNICATION BLOCK

PARAMETER	VALUES
Baud rate	38400, 19200, 9600, 4800, 2400 and 1200
Data bits	8
Parity	None, even, odd
Stop bits	1, 2

The factory defaults are 19200 baud, 8 data bits, even parity and 1 stop bit (19200 – 8E1).

Status flags

DEVICE COMMON BLOCK					
PARAMETER	ADDRESS	R/W	SZ	LEVEL	DESCRIPTION
IR_STATUS_FLAGS	34	R	U	All	Device Status flags (0 = status OK)

2.2.

VALUE	STATUS WHEN 1	REMARKS
0000 0000 0000 000X	Hardware error detected	Contact your supplier
0000 0000 0000 00X0	Soiling data error	Measurement out of range. Could happen after a bad local dust calibration or as a result of damaged glass.
0000 0000 0000 0X00	ADC error	
0000 0000 0000 X000	Flash error	Memory problem, potentially after a bad firmware upgrade. Retry the upgrade
0000 0000 000X 0000	Tilt sensor error	
0000 0000 00X0 0000	Humidity error	Internal humidity sensor reports a level too high for proper operation
0000 0000 0X00 0000	Calibration error	Will be set if there is a calibration error. This bit will be reset at startup of new calibration session
0000 0000 X000 0000	Tare error	Will be set if there is a serious problem during taring. No clean measurement is started
0000 000X 0000 0000	Not used	
0000 00X0 0000 0000	Not used	
0000 0X00 0000 0000	Not used	
0000 X000 0000 0000	Not used	
000X 0000 0000 0000	Watch dog error	A process timed out, try a power off / power on
00X0 0000 0000 0000	Not used	
0X00 0000 0000 0000	Not used	
X000 0000 0000 0000	Not used	

2.2.1.   Calibration status Before local dust calibration (refer to the last update of DustIQ instruction sheet for further details, from the website).

DEVICE COMMON BLOCK					
PARAMETER	ADDRESS	R/W	SZ	LEVEL	DESCRIPTION
IR_CALIBRATION_STATUS_BEFORE	26	R	U	All	Calibration status before start. Volatile, live value.

VALUE	MEANING	REMARKS
0	There is not enough sun light and not enough soiling on the sensors	Check if there's a clear sky on-site and that it is max. 2 hours before or after local solar noon. Check if there is >3% transmission loss in registers 21 and 25
1	Enough sunlight	There is > 500 W/m² solar irradiation on the DustIQ. This you'll see every sunny day. But not (yet) enough soiling so wait for more soiling.
2	Enough soiling on both sensors	There is >3% transmission loss in registers 21 and 25 But not enough sunlight (yet)
3	**Enough sunlight and soiling on both sensors**	Contact people on-site to check readiness, time window and sky conditions and if OK they can start the 2 minute waiting time followed by pushing the button and cleaning.
4	Unstable soiled measurements	Before calibration the DustIQ must have had 2 minutes of stable sunlight and the two sensors must have had 2 minutes of stable soiling.

2.2.2

Calibration status After local dust calibration.

DEVICE COMMON BLOCK					
PARAMETER	ADDRESS	R/W	SZ	LEVEL	DESCRIPTION

DEVICE COMMON BLOCK					
IR_CALIBRATION_FLAGS	**27**	R	U	All	Calibration status after. Stored, non-volatile value.

VALUE	MEANING	REMARKS
0	Calibration successfully started	- "0" is also showing during the calibration process until an error occurs or completed successfully
1	**Successful calibration**	The dust slopes in registers 36 and 38 will have changed. Refer to chapter 8.2 to see how older data or data from other DustIQs on the same PV plant can be updated with the new calibration values. Valid values for register 36 and 38 are from 30 (extreme white soiling) to 300 (very dark soiling)
1000	Attempted start without enough sun	Calibration was halted. Nothing has been changed. Register 26 should be checked before pushing the button.
1001	Attempted to start without enough soiling	Calibration was halted. Nothing has been changed. Register 26 should be checked before pushing the button.
1002	Attempted start with unstable sunlight on PV cell	There can haven been clouds or on-site personal blocking the sunlight in the 2 minutes before pushing the button.
1003	Attempted start with unstable dust measurement.	On-site personnel touched the glass area of sensor 1 or 2 during the 2 minutes before pushing the button.
1004	Button pushed but too short. This prevents accidental start.	Push the button 3-5 seconds for the calibration to start.
1005	Time out. The button hasn't been pushed a second time within 2 minutes from first push.	Could be by accident. Not pushing the button a second time is also a safe escape from the calibration procedure.
1006	System is not ready yet for calibration	The system stabilizes for the first 3 minutes at start-up. It's not possible to tare or calibrate the system during this start-up time.
2010	Sensor 1 showed too little soiling change.	Sensor 1 not properly cleaned or dried.
2020	Sensor 2 showed too little soiling change.	Sensor 2 not properly cleaned or dried.
2030	PV cell showed unreliable change.	- PV cell not properly cleaned or dried. - PV cell much cleaner than the sensors by e.g. accidental cleaning. - Sun blocked by clouds or personnel during the 1 minute measurement.
2040	Clean measurement unstable.	Somebody might have touched a sensor during the 1 minute measuring period.
2050	DustSlope out of range.	Calculated dust slope not within **expected** range (30 .. 500). Cause could be insufficient cleaning or unstable solar light.
2060	DustSlope factor out of range.	See above but so severe that the original dust slopes are **not** changed.

Register 27 after tare

VALUE	MEANING	REMARKS
3000	Tare successful	Tare procedure is completed
3006	Tare started within 2 minutes of start up	Attempted to start tare procedure without waiting the required 2minutes to allow for stabilization.
3010	Hardware error	Signal is to low possible hardware failure
3020	TARE_STATUS_CODE_TIMEOUT	Clean measurement not finished within timeout of 3 minutes. Serious problem.

For local dust calibration it is strongly advised to take close up pictures of the DustIQ sensors and PV cell before and after cleaning. This to help identify possible errors that have been made during the calibration.

Check cleaning activity on-site means that one of the steps wasn't performed according to the procedure or clouds passed by or a person cast a shadow on the DustIQ at the time of the first button push or in the 1 minute after the second button push.

Reset to factory dust calibration
Press DustIQ calibration button for a minimum of 15 seconds. Then the sensors will flash every 2 seconds for about 15 seconds. The calibration button will flash every 1 second also for 15 seconds long.
The dust slope registers 36 and 38 will be reset to factory default, as mentioned in the calibration certificate which comes with DustIQ.

Sample ModbusPoll data for data model 3.x

Tx = 3: Err = 0: ID = 1: F = 04: SR = 1000ms

3.

	Alias	00000	Alias	00010	Alias	00020	Alias	00030
0	Device type	800		60	SR1	1009		25158
1	Model	301		0	TL1	-9	PVtemp	0
2	Software	11088		0		0	mVolt	3182
3	Year	15		0		0	Status	1
4	Serial	1		0	SR2	1012	Flags	0
5	hardware	5		0	TL2	-12		0
6	Cal yr	2018		0		9955		78
7	Cal mnth	5		0		9984		0
8	Cal day	15		0	TiltX	0		73
9		0		0	TiltY	0		0

The DustIQ makes a difference between a holding register and an input register. **Only use 04 Read Input Registers** to get data from the DustIQ.

4. # Tilt sensor output

Below are the Modbus registers and sample output depending on correct and incorrect mounting.

TILT SENSOR BLOCK					
PARAMETER	ADDRESS	R/W	SZ	LEVEL	DESCRIPTION
IR_TILT_X_DIRECTION	28	R	S	All	**Tilt X direction (long axis) -179.9 to +180.0 in steps of 0.1 degree**
IR_TILT_Y_DIRECTION	29	R	S	All	**Tilt Y direction (short axis) -179.9 to +180.0 in steps of 0.1 degree**
RESERVED	30	R	S	All	Reserved for future expansion

4.1.

Tilt sensor readings in several positions

The tilt is reported in 0.1 degrees thus angle of e.g. 34.7 degrees is reported as 347.

In the shown position, Tilt x and y are close to zero.
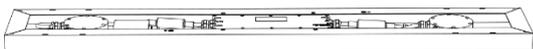
In the shown position, Tilt x is zero and Tilt y is -1800
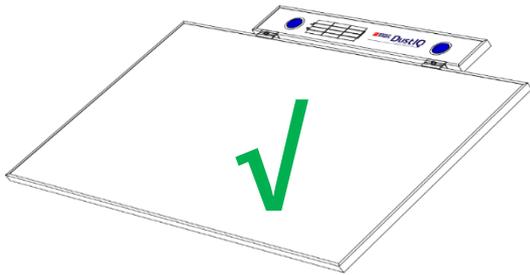
In the shown position, Tilt x ≈ 0 and Tilt y is between 0 and 900.

This way the DustIQ must have a supporting structure. Measurements will not reflect vertical soiling gradient.
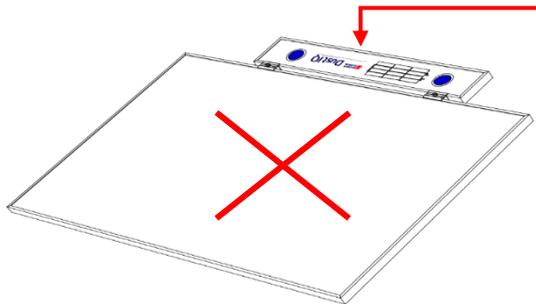
In the shown position, Tilt x ≈ 0 and Tilt y is between -900 and 0.
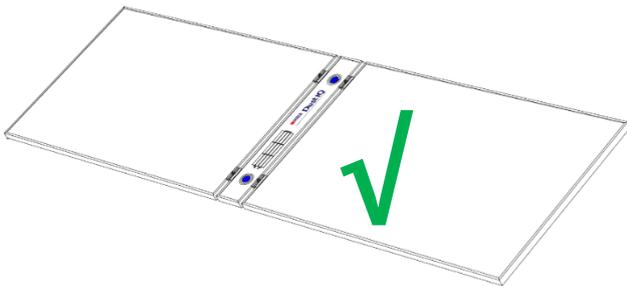
In the shown position (DustIQ is between panels or on the side), Tilt x is between 0 and 900 and Tilt y ≈ 0.
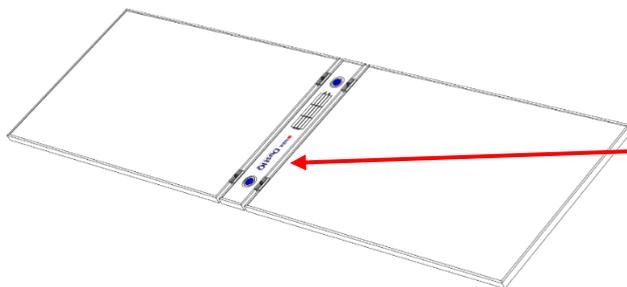
In the shown position (DustIQ is between panels or on the side), Tilt x is between -900 and 0 and Tilt y ≈ 0.

Reset using Modbus Write coil commands

Depending on the firmware, the DustIQ offers one or two reset capabilities.

Full Factory reset valid for **all** firmware versions

This reset restores **all** settings to default, including resetting the communication parameters to 19.200 baud, 8 bit, 1 stop bit, even parity and the factory dust calibration. The reset works on all firmware versions.

5.

The DustIQ will **not** go back to the previous dust calibration if one was made earlier but to the **factory** dust calibration.

5.1. If the SCADA system allows Modbus® commands to be programmed and send, then it can be done remotely without local intervention.

Otherwise connect the DustIQ to an RS485-USB interface and to a suitable 12-30V power supply, in-situ or in the office.

Start ModbusPoll or QModMaster or equivalent software
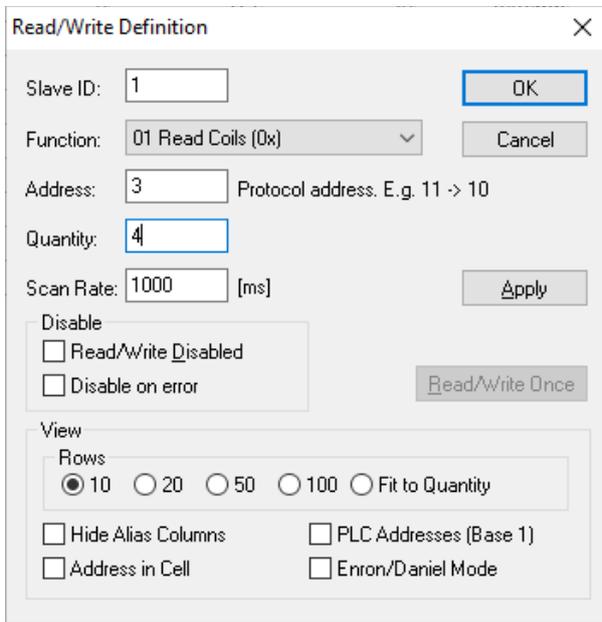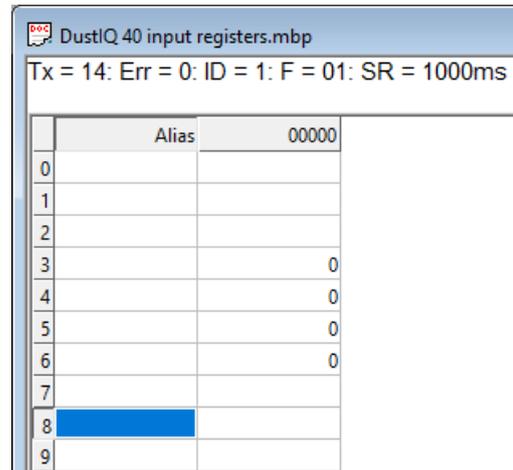
Example settings for a DustIQ at Modbus address 1   *The coils 3 -7 are read as shown above:*

Double click on the value of the desired register to switch the value to **On** and click Send.

Start with double clicking on register **5**.
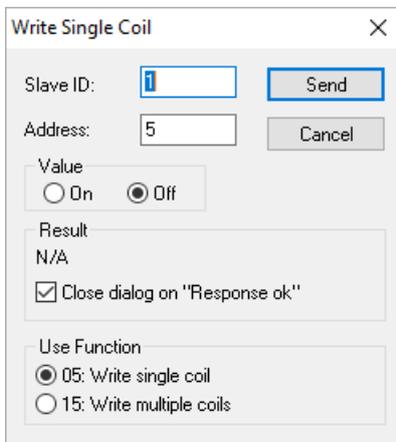
Do this three times in the **5-3-6 order**:

1) Switch coil 5 to ON = Reset to factory config
2) Switch coil 3 to ON = Apply update
3) Switch coil 6 to ON = Reset instrument or you can perform Power Off and On

After the sequence the DustIQ gives a very short blink of the sensor LEDs. The switched coils will be reset.

Dust Calibration reset

The following Modbus driven reset only works on firmware 11.148 and above.

!
●

The DustIQ will **not** go back to the previous dust calibration if one was made earlier but to the **factory** dust calibration.

If the SCADA system allows Modbus® commands to be programmed and send, then it can be done remotely without local intervention.

5.2.

Otherwise connect the DustIQ to an RS485-USB interface and to a suitable 12-30V power supply, in-situ or in the office.

Start ModbusPoll or QModMaster or equivalent software.

Example settings for a DustIQ at Modbus address 1

The coils 3 -8 are read as shown above:

Double click on the value of the desired register to switch the value to **On** and click <u>**Send**</u>.

Start with double clicking on register **8**.

Do this three times in the **8-3-6 order**:

4)   Switch coil 8 to ON = Reset to factory config
5)   Switch coil 3 to ON = Apply update
6)   Switch coil 6 to ON = Reset instrument or you can perform Power Off and On

After the sequence the DustIQ gives a very short blink of the sensor LEDs. The switched coils will be reset.

Open source licenses

The following software is used in this product:

CMSIS	https://developer.arm.com/embedded/cmsis	ARM Limited	Apache License 2.0
mbed library	https://os.mbed.com	ARM Limited	Apache License 2.0
mbed tls library	https://tls.mbed.org	ARM Limited	Apache License 2.0

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Example Campbell programs

The following programs are short examples of how to read and store data from a DustIQ connected to either a CR100X or CR6. Both of these have native RS-485 and Modbus support.

<ins>CR6 example:</ins>

7.
```
'For programming tips, copy this address to your browser
'https://www.campbellsci.com/videos/datalogger-programming
'CR6 Series Datalogger
'Date: 10-10-2018 Program author:Donald van Velsen
'Declare Constants
'Example:
'CONST PI = 3.141592654 or Const PI = 4*ATN(1)

'Program to read the soiling and transmission loss registers of a DustIQ

'Result stores the outcome of the modbus communication. if succesfull the result is 0.
'If communications failed with the DustIQ result will increment with 1
Public Result

'Data array to store read out value
Public SRSensors(8) As Long
'Alliasing of the array to increase readability of the data table
Alias SRSensors(1) = Soiling_ratio_sensor_1
Alias SRSensors(2) = Transmission_loss_sensor_1
Alias SRSensors(3) = Reserved_sensor_1_1
Alias SRSensors(4) = Reserved_sensor_1_2
Alias SRSensors(5) = Soiling_ratio_sensor_2
Alias SRSensors(6) = Transmission_loss_sensor_2
Alias SRSensors(7) = Reserved_sensor_2_1
Alias SRSensors(8) = Reserved_sensor_2_2
Alias SRSensors(9) = TiltX_direction
Alias SRSensors(10) = TiltY_direction
Alias SRSensors(11) = Reserved_Tilt
Alias SRSensors(12) = Back_Panel_Temp

'DustIQ modbuss address,
Public SensorMBAddress(1)= {3} As INT 'the one on my desk had address 3

'Communication port to be used on datalogger
'ComC1 = data - is grey wire in Kipp cable
'ComC2 = data + is yellow wire in Kipp cable

Const SensorPort = ComC1 'DustIQ on a cr6 it is ComC1 or ComC3 see Campbell manual

'datatable to record the data
'in this case only the two soiling ratio's are stored
DataTable(DustIQ,True,-1)
        DataInterval(0,1,min,10)
  Sample(2,Soiling_ratio_sensor_1,Long,False) 'Soiling_Ratio_sensor 1
  Sample(2,Soiling_ratio_sensor_2,Long,False) 'Soiling_Ratio_sensor 2
  Sample(2, TiltX_direction,Long,False)       'TiltX_direction
  Sample(2, TiltY_direction,Long,False)       'TiltY_direction
  Sample(2, Back_Panel_Temp,Long,False)       'Panel temperature
EndTable

'Main Program
BeginProg
  'declare variable blnOpen, if true communication port is succesfully opened
  Public blnOpen As Boolean

  'Open the serial port, 8 bits, even parity, 19200 baud, optional param "4" at end for RS485 half-duplex
on cr6
  blnOpen=SerialOpen(SensorPort,19200,2,0,200,4)   'even parity

  'scan the registers 20 and 21 for sensor 1, registers 24 and 25 for sensor 2.
  'note that they are incremented with 1.
  Scan (1,min,0,0)
        'ModbusMaster ( ResultCode, ComPort, BaudRate, ModbusAddr, Function, Variable, Start, Length,
Tries, TimeOut, [ModbusOption] )
        ModbusMaster (Result,SensorPort,19200,SensorMBAddress(1),4,SRSensors(1),21,2,3,10,1)
'Sensor1 Soiling Ratio & Transmission Loss read
        'register 21 & 22 read. register 22 & 23 are reseverd at this time
        ModbusMaster (Result,SensorPort,19200,SensorMBAddress(1),4,SRSensors(5),25,2,3,10,1)
'Sensor2 Soiling Ratio & Transmission Loss read
        'register 25 & 26 read. register 27 & 28 are reserverd at this time
        ModbusMaster (Result,SensorPort,19200,SensorMBAddress(1),4,SRSensors(9),28,4,3,10,1)       'Tilt X
& Y, reserved and Panel Temp
  'Store data to table
        CallTable DustIQ
  NextScan
EndProg
```

CR1000X example:

```
'Program to read the soiling and transmission loss registers of a DustIQ

'Result stores the outcome of the modbus communication. if succesfull the result is 0.
'If communications failed with the DustIQ result will increment with 1
Public Result

'Data array to store read out value
Public SRSensors(8) As Long
'Alliasing of the array to increase readability of the data table
Alias SRSensors(1) = Soiling_ratio_sensor_1
Alias SRSensors(2) = Transmission_loss_sensor_1
Alias SRSensors(3) = Reserved_sensor_1_1
Alias SRSensors(4) = Reserved_sensor_1_2
Alias SRSensors(5) = Soiling_ratio_sensor_2
Alias SRSensors(6) = Transmission_loss_sensor_2
Alias SRSensors(7) = Reserved_sensor_2_1
Alias SRSensors(8) = Reserved_sensor_2_2
Alias SRSensors(9) = TiltX_direction
Alias SRSensors(10) = TiltY_direction
Alias SRSensors(11) = Reserved_Tilt
Alias SRSensors(12) = Back_Panel_Temp


'DustIQ modbuss address,
Public SensorMBAddress(1)= {1} As INT  '
standard factory setting Modbus address

'Communication port to be used on datalogger
'ComC5 = data - is grey wire in Kipp cable
'Comc6 = data + is yellow wire in Kipp cable

Const SensorPort = comC5 'DustIQ on a cr1000x  comC5 and comC6 canbe used, on a cr6 it is ComC1 or ComC2 see
Campbell manual

'datatable to record the data
'in this case only the two soiling ratio's are stored
DataTable(DustIQ,True,-1)
        DataInterval(0,1,min,10)
  Sample(2,Soiling_ratio_sensor_1,Long,False) 'Soiling_Ratio_sensor 1
  Sample(2,Soiling_ratio_sensor_2,Long,False) 'Soiling_Ratio_sensor 2
  Sample(2, TiltX_direction,Long,False)         'TiltX_direction
  Sample(2, TiltY_direction,Long,False)         'TiltY_direction
  Sample(2, Back_Panel_Temp,Long,False)         'Panel temperature

EndTable

'Main Program
BeginProg
  'declare variable blnOpen, if true communication port is succesfully opened
  Public blnOpen As Boolean

  'Open the serial port, 8 bits, even parity, 19200 baud, optional param at end for RS485 half-duplex
  blnOpen=SerialOpen(SensorPort,19200,2,0,200)    'even parity

  'scan the registers 20 and 21 for sensor 1, registers 24 and 25 for sensor 2.
  'note that they are incremented with 1.
  Scan (1,min,0,0)
        'ModbusMaster ( ResultCode, ComPort, BaudRate, ModbusAddr, Function, Variable, Start, Length, Tries,
TimeOut, [ModbusOption] )
        ModbusMaster (Result,SensorPort,19200,SensorMBAddress(1),4,SRSensors(1),21,2,3,10,1)       'Sensor1
Soiling Ratio & Transmission Loss read
        'register 21 & 22 read. register 22 & 23 are reseverd at this time
        ModbusMaster (Result,SensorPort,19200,SensorMBAddress(1),4,SRSensors(5),25,2,3,10,1)       'Sensor2
Soiling Ratio & Transmission Loss read
        'register 25 & 26 read. register 27 & 28 are reserverd at this time

        ModbusMaster (Result,SensorPort,19200,SensorMBAddress(1),4,SRSensors(9),29,4,3,10,1)        'Tilt X
& Y, reserved and Panel Temp

  'Store data to table
        CallTable DustIQ
  NextScan
EndProg
```

Appendix B

How to value dust measurements

Measuring dust is a new area with new challenges. Below are a few of them explained.

Introduction

1. DustIQ is not an indicator of dust, but a real accurate measurement device, in line with all Kipp & Zonen instruments. The DustIQ measurement technology is unprecedented and new to the market. Therefore some extra words for the user of the measurement information.

1.1. One should understand that measuring physical quantities needs careful interpretation. Measuring voltage or velocity can be done very precise, and the answer is always very close to the truth. Influenced only by the accuracy of the used instrument. Much more difficult it gets for instance with precipitation or solar radiation measurements; there is an intrinsic limit as to how precise one can measure it and with which uncertainty.

Measuring dust / transmission loss /soiling ratio is a new field of science. There are many opinions about it, but there is no large history of data and experience in measurements. Although the spot measurement of DustIQ is very precise, it is wise to do interpretation and use common sense when extrapolating the measurement value to the whole PV plant, or a part of it, for decision-making. The coming years, Kipp & Zonen will build up this expertise together with you and our other customers and scientific users. Visual inspection seems the most logical validation for understanding and extrapolating the dust measurement information. Before decision making and taking cost intensive cleaning actions, it is recommended to do visual inspection: is the DustIQ device soiled in the same way as the average soiling on the PV modules? What helps in data validity, is the fact that the DustIQ is designed to handle local irregularities of soiling, and that the DustIQ has two measurement sensors, so one can compare the values.

For larger areas, it is wise to mount several DustIQs, just like you now mount several pyranometers across a PV plant. Again: for DustIQs, one can trust the measurement value to be correct, the only judgement you have to make, is, whether this value is representative for the whole PV park.

1.2. ### Solar angle dependency

The actual transmission loss and soiling ratio have a solar angle dependency. The DustIQ is not aware of the solar angle, but based on our test results and literature research we have two simple formulas to calculate the <u>daily</u> SR and TL averages.

$$SR_{DAILY\_AVERAGE} = 1.2 \times SR_{DUSTIQ} - 20 \qquad and \qquad TL_{DAILY\_AVERAGE} = 1.2 \times TL_{DUSTIQ}$$

Background: For the customer a very useful value is to know the weighted average value for the Soiling Ratio over a day. Such a weighted average value is also prescribed by the IEC 61724-1 norm (Annex C). We have chosen a weighting by PV power output over the course of the day.

For this calculation, we have chosen multiple locations:

1)   Close to the Dubai Mohammed bin Rashid Al Maktoum Solar Park in Dubai.
2)   Close to planned new Solar Park in Baganuur near Ulaanbatur in Mongolia.

Dubai Mohammed bin Rashid Al Maktoum Solar Park
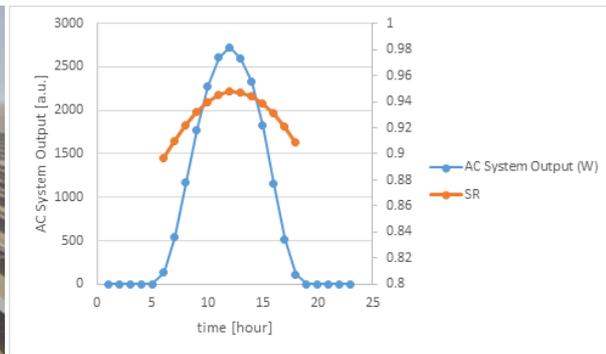
Hypothetical PV AC output at the 8th of august 2017 in Dubai
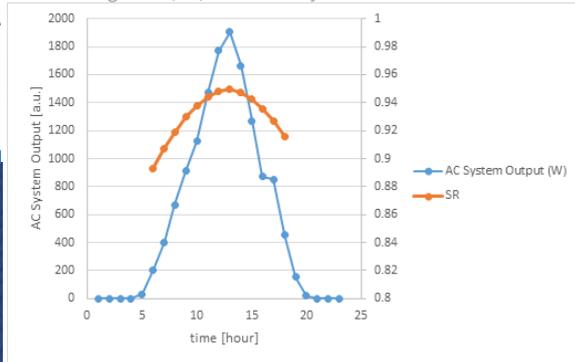
Hypothetical PV AC output at the 6th of august 2017 in Mongolia and SR over the day.

Combining the information from both graphs, we calculated the SR$_{DAILY\_AVERAGE}$ weighted by the PV output for both locations and concluded that there is very little difference between Dubai (latitude= 24.4) and Mongolia (latitude = 47.9)

1.3. The influence of dew and rain

The DustIQ measurement are sensitive to dew and rain and measurements done during these conditions **must** be ignored.

It's the trend line over a longer period of time that gives the best overview of the transmission loss.

Soiling Ratio at Green Energy Park in Ben Guerir
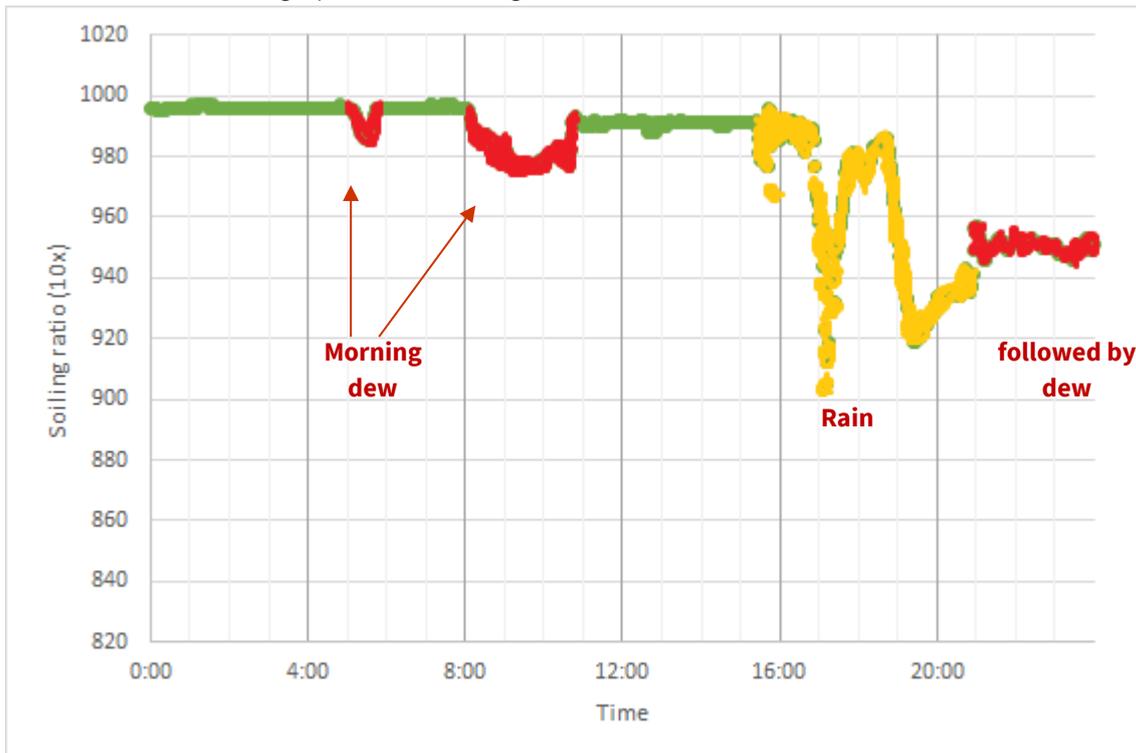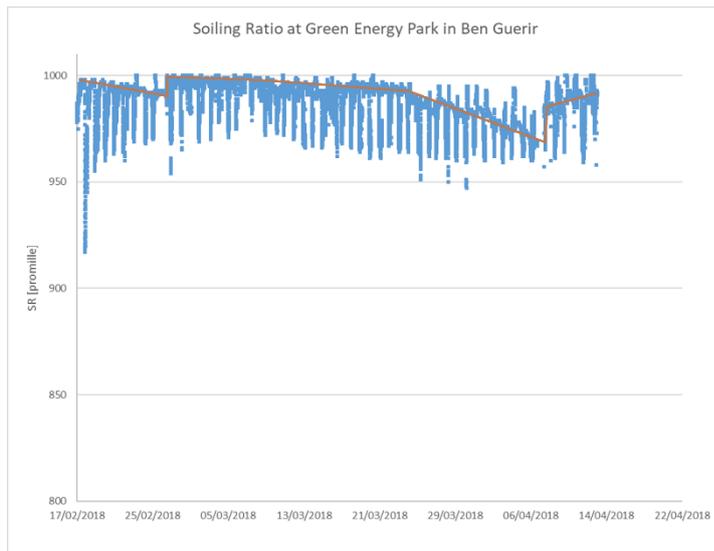
The visible spikes are due to morning and evening dew. The bigger, longer lasting changes are the result of rain cleaning the panel.

The DustIQ performs a measurement every minute, but since the accumulation of dust is a very slow process, one doesn't need to read and record a measurement every minute. By using data from a weather station (to ignore dew, rain, snow events ..), it is possible to select enough valuable measurements per day to show the soiling build up trend line.

Filtering data based on the combined PV module temperature and calculated dewpoint based on local ambient temperature plus relative humidity or the dewpoint as provided by a weather station plus a rain gauge has proven to be useful.

Selection criteria:
- PV module temperature > 2 degrees Celsius higher than the dew point.
- No rain 1 hr before and 4 hours after.
- No snow. (this results in very high reflection and DustIQ output changes)
- No change in transmission loss in the last 24 hours of >5% unless the DustIQ has been cleaned.

Taking only few measurements per day improves the readability of the chart.

Soiling Ratio at Green Energy Park in Ben Guerir (raw data)
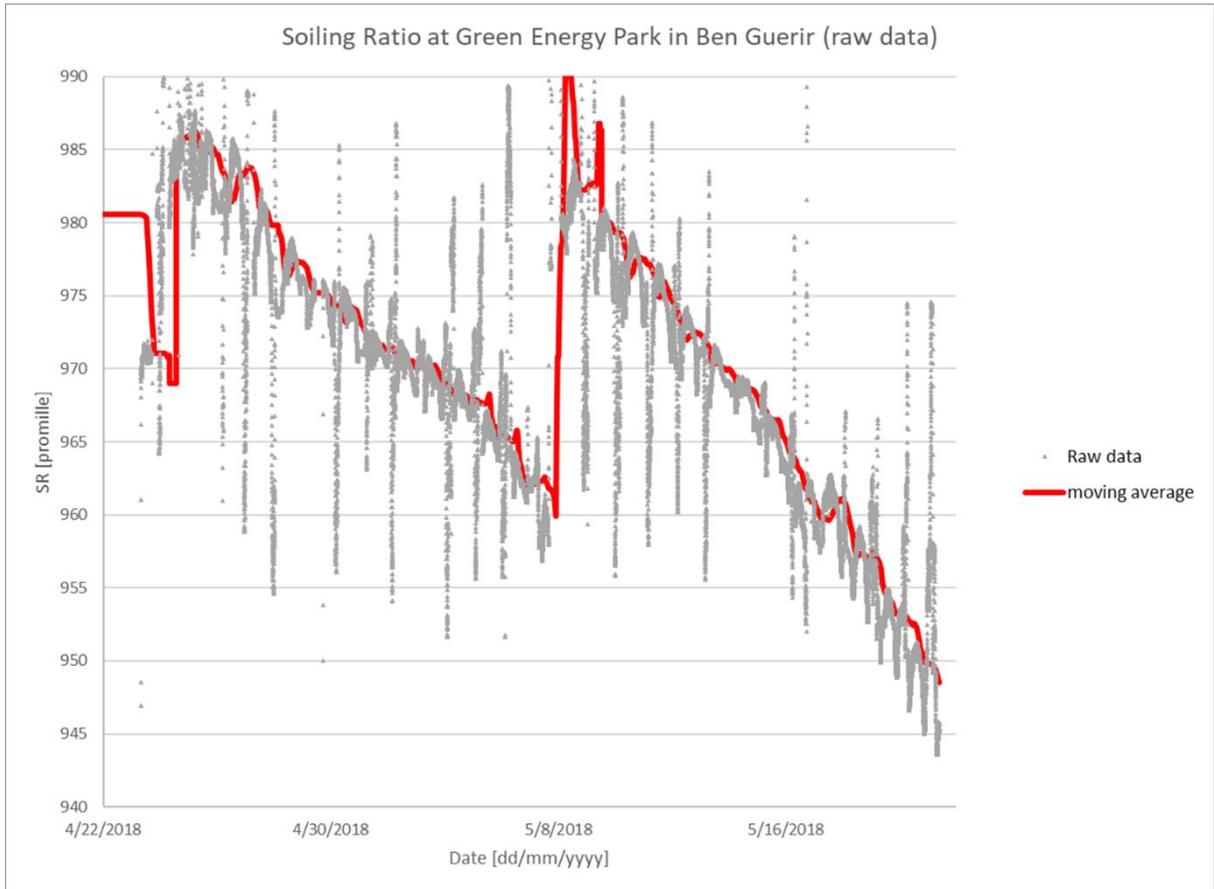
The above sample data shows the data collected in Morocco with daily dew and occasional rain. Still the trendline in soiling build-up is clearly visible.

Soiling ratio Morocco
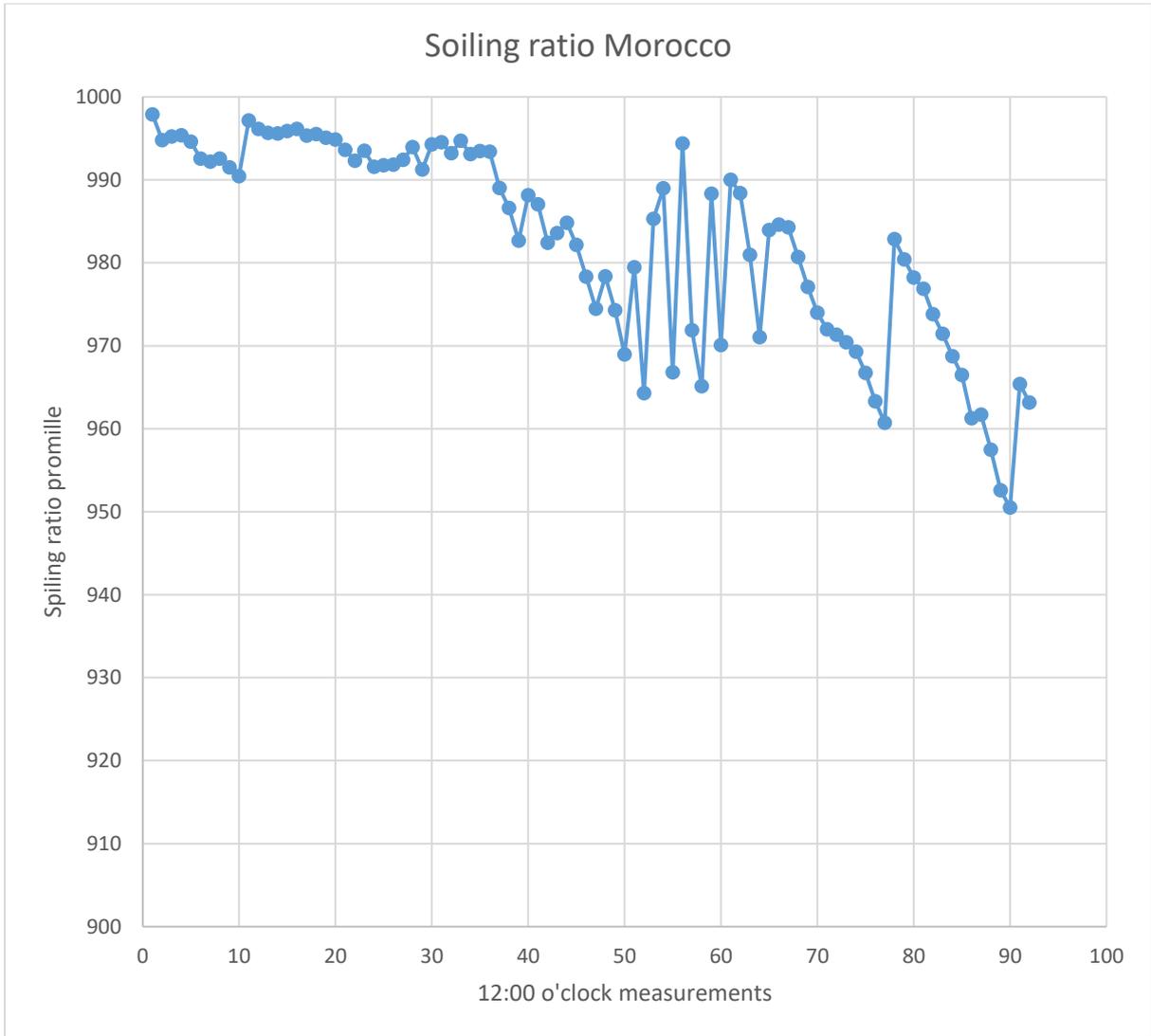
With all dew and rain events removed from the data.

Daily average soiling ratio's

Please also check: https://www.kippzonen.com/Download/1022/DustIQ-Application-Note-Data-Reduction
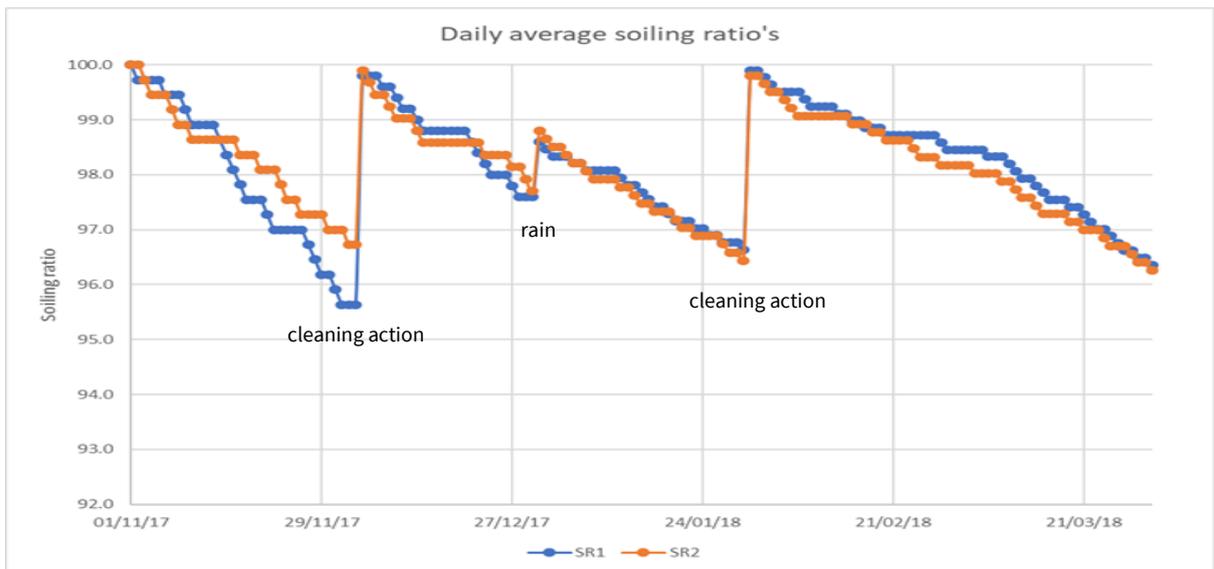
Resources for dewpoint calculations: https://en.wikipedia.org/wiki/Dew_point

Dealing with small offsets in transmission Loss or Soiling Ratio

When a DustIQ is completely clean the sensors are not measuring zero reflection of the pulsed blue LED light. There is some reflection from the glass. With soiling added there will more reflection and the increase is translated into transmission loss.
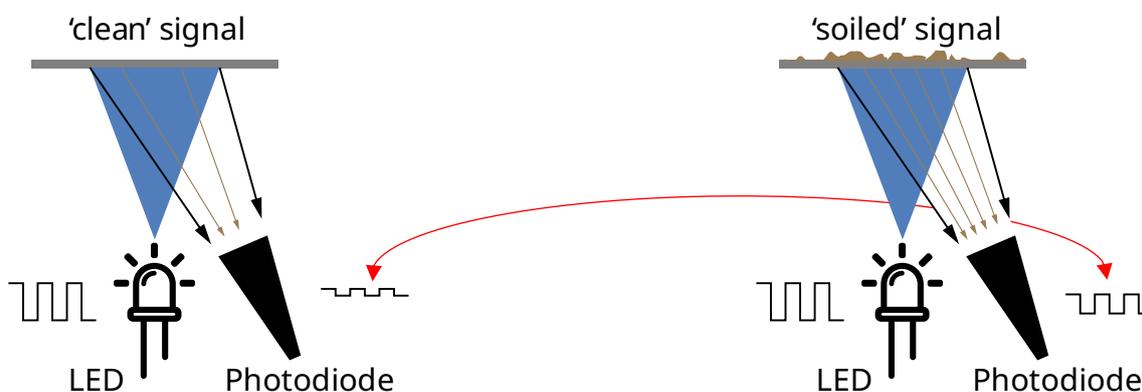
This means that there is a reflected light signal that represents zero transmission loss (0% TL) and there is an uncertainty in determining this value during the factory calibration process.

The result could be a small zero offset that is a maximum of ±1%. In practice, it is unlikely to exceed ±0.4% and it remains stable.

In case of need, please refer to taring instructions within the DustIQ instruction sheet (last update can be downloaded from the website)

Appendix C – FAQ Frequently Asked Questions

The most frequently asked questions are listed below. For an update or further information refer to our website at www.kippzonen.com

Q: Does the DustIQ work with snow?
A: No the current DustIQ will report a very high transmission loss, not related to the real transmission loss a PV panel with similarly snow cover would experience.

Q: The dust slopes in registers 36 and 38 didn't change after a local dust calibration.
A: Somewhere in the procedure a check failed. See paragraph 12 to help you interpreting the error codes.

Q: My DustIQ doesn't flash every minute.
A: This is a serious condition and when you're sure that proper power (12-30V, 500mA) is supplied to the DustIQ and it doesn't change after a power off – power on sequence, you will have to contact Kipp & Zonen or your local representative.

Q: My DustIQ flashes but I get no data.
A: Are your communication parameters setup correctly (factory standard is 19200, 8E1) and are Data + and Data- lines connected correctly?
Does your data logger have the right native support for RS-485 Modbus RTU to Modbus servers ?. Sometimes the RS-485 is for communication between data loggers only and does not properly support Modbus.

Q: Why is my PV panel temperature sensor giving strange readings?
A: Is the temperature sensor connector plugged properly? Is the sensor itself installed properly and still on the back of the PV panel and in the right place? With a double sided tape used, it's unlikely for the sensor to come lose, unless the PV panel wasn't cleaned properly before installation.

Q: What does DustIQ measure?
A: The DustIQ measures the amount of light reflected by the dust back into the sensor. This is converted into Transmission Loss (TL) and Soiling Ratio (SR). The DustIQ reports 2 independent transmission losses and soiling ratios (of its 2 sensors). Where TL = 100% - SR

Q: How does soiling loss translate into power/energy loss?
A: Transmission loss, according to several publications and reports, directly translates into energy loss because the relationship is almost linear for soiling losses up to 20%.

Q: What is the accuracy of dust measurement by the DustIQ?
A: Transmission Loss measurement Accuracy: ± 10% of reading after local dust calibration (not including zero offset). Zero offset: less than ± 1% when clean.

Q: What can I do with the zero offset?
A: The zero offset can be subtracted from the measurements to reach zero again. E.g. a Transmission Loss of 0.3% for a completely clean DustIQ is within specification and can be compensated by $TL_{CORRECTED}$ = TL - 0.3 or Soiling Ratio$_{CORRECTED}$ = Soiling Ratio + 0.3
See DustIQ instruction sheet (attached with new DustIQ units or downloaded from the website) for instructions on dealing with offsets.

Q: How closely do dust levels on sensor and PV plant panels match?
A: When installed next to or in between the actual PV modules, the relationship is between 80 and 100%.

Q: Is the Dust IQ soiling loss accurate when compared with a 2-panel system?
A: A two-panel system with PV modules identical to the ones used in the PV plant and cleaned every day is the most accurate but also most expensive/cumbersome solution. It is also very unlikely that a two-panel system can be installed right among the real PV modules and thus the soiling will be different. The DustIQ is the optimum balance between accuracy and being maintenance-free with a low TCO.

Q: What is the maximum soiling measurement range of DustIQ?
A: The DustIQ can measure up to 50% soiling loss.

Q: How can the soiling be the same as on the panels?
A: The DustIQ is installed next to or in between the actual PV modules and will get the same dust, wind, rain and cleaning. The surface is also very similar to many PV commercial modules.

Q: What is the significance of the solar cell on the DustIQ?
A: The silicon cell (on DustIQ) is only used once, for the local dust calibration to correlate the step change in energy with the optical sensor measurement.

Q: What is the impact of the panel temperature on the DustIQ?

A: The DustIQ uses its own Optical Soiling Measurement, so its performance is not affected by temperature (within the given range in tech specifications: from -20 to +60° C).

Q: What is the purpose of the temperature option when selecting the correct model of DustIQ?

A: The PV module temperature sensor (now always present) can be connected to the second port on the DustIQ to measure the rear temperature of a nearby PV module. The IEC advises to take many temperature measurements to be able to take the PV module temperature into account in the Performance Ratio calculations.

Q: How many DustIQs are needed relative to the installed PV plant power? (Number of sensors per 1 MW)

A: The standard IEC61724-01 on monitoring gives recommendations. Due to copyright we cannot share the document. Table 1 in IEC document advises as follows:

Up to 5MW:	1 instrument
Up to 40MW:	2 instruments
Up to 100MW:	3 instruments
Up to 200MW:	4 instruments
Up to 300MW:	5 instruments
Up to 500MW:	6 instruments

Please see here for a preview and ways to buy the document.

Q: Technically speaking, how does the DustIQ measure soiling according to IEC 61724?

A: IEC 61724 specifies two methods to measure soiling:

Method 1: max power and temperature of the soiled device
Method 2: short-circuit current and temperature measurement

The DustIQ output is equivalent to the short-circuit current method. Obviously it does not measure short-circuit current but the reflected light, that then is translated into transmission loss. The local dust calibration is done based on the step change of the short-circuit current of the built-in silicon panel.

Q: Is the DustIQ useful for Polycrystalline or Thin-film modules?

A: Yes, it is. Although the Thin-film might react a little bit different, the relationship between sunlight lost due to soiling and energy loss remains the same.

Q: What is the expected soiling loss percentage with respect to dry cleaning and wet cleaning?

A: This question is best answered by the people supplying the dry cleaning robots. However, we have seen dry cleaning robots to reach 0.5% soiling loss compared to 8% loss before the cleaning. Wet cleaning sometimes is better but only when done very carefully, with very clean water and in absence of wind that brings new dust directly sticking to the wet PV modules.

Q: Can we trigger automatic movement of robotic cleaners for cleaning of modules through RS-485?

A: The short answer is no. As the produced data by DustIQ needs "clever" robot control software to filter out rain and dew events, to be able to initiate a cleaning cycle. While humans can recognize immediately the situation form output graph and the weather report. In order to let the robot clean automatically, a machine learning and AI systems must be implemented (which can be possible in the future).

Q: Can the soiling data be transmitted to SCADA via Wi-Fi?

A: The DustIQ doesn't include Wi-Fi (as many customers don't trust connection availability at all the time). Therefore, Modbus RTU is used over RS-485 wired connection, that also supplies the 12-24V power. However, the solution can be made wireless by using an integrator or customer supplied RS-485 to Wi-Fi converter and Modbus over TCP/IP.

Q: Can we link DustIQ to SCADA system to measure the Performance Ratio (PR)?

A: Absolutely. The DustIQ produces Modbus registers to be read. Please check the manual.

Q: Can DustIQ resist harsh conditions, for example in locations near the sea?

A: Yes. The DustIQ is made out of glass and aluminium with PV standard quality. Thus the same procedures/conditions for using and cleaning PV modules apply.

Q: Is there a way to identify the soiling rate on the glass dome of a pyranometer using the DustIQ?

A: There is no direct relationship between the soiling of the flat DustIQ and the round glass dome of a pyranometer. Also the influence of soiling on a round dome on the solar radiation measurement changes from plus to minus over the day and with the angle of the sun. Currently, there is no better solution than regular cleaning of the dome.

Q: What is the advantage of using blue LED light?

A: Only blue LEDs can be guaranteed (by the manufacturer) to show long time stability in UV rich environment.

Q: Why can the reported soiling ratio differ between the two sensors of the DustIQ?

A: Analyses show that the bottom of PV modules often gets soiled more than the top part and so will the bottom DustIQ sensor. Resulting in higher reported transmission loss

Q: Following IEC 61724-01, would you recommend measuring soiling in heavy rainy areas, e.g. Quebec in Canada?

A: According to IEC 61724-01, soiling monitoring is necessary when energy losses can exceed more than 2%. In areas with a lot of rainfall, this probability is very small and measuring soiling would not be needed.

Q: How fast can the DustIQ report data?

A: The DustIQ takes a measurement once per minute. It operates throughout the whole day. The measurements are reliable as long as the device is dry. Storing 24x7 measurements of every minute does not really make sense as soiling grows very slowly. A few measurement points per day are enough.

Q: The DustIQ is obviously smaller than a solar panel. By saying "it has PV panel dimensions", what does that mean?

A: DustIQ device length (996 mm) is the most common width of PV modules, also its height (35mm). in addition, the used aluminium frame and glass are same as used in PV module.

Q: Can DustIQ automatically perform the averaging of many data points?

A: No, it cannot. Thanks to its measurement principle, DustIQ does not need that to improve accuracy.

Q: What if the soiling build-up does not look the same on the DustIQ collection area compared to other modules?

A: Theoretically, the DustIQ measurement could be different then. According to the experience our customers shared, the results are still close enough.

Q: Many PV plants are installed near the ocean or industrial areas. What do you recommend to handle bird droppings and organic material or soot?

A: Bird droppings are very local and only a 2-panel system can work accurately. However, preventing bird colonies even when building the PV plant is paramount. Cleaning is very difficult or expensive and once colonized, the birds are difficult to deter.

Q: What is the main difference between normal soiling station of other makes and DustIQ?

A: Normal 2-panel systems require daily cleaning of the clean reference cell or panel, they do not fit in between the real PV modules, not to mention the extra cost and unpractical side. The DustIQ works 24/7 as long as the DustIQ is free from rain or dew. It even works up-side-down for bifacial PV plants.

Q: How does the DustIQ compare to the Atonometrics MARS sensor?

A: They both use optical soiling measurement. The MARS uses a camera and only works around sunset and with a clear sky. Thus, one measurement window per day. The DustIQ measures accurately 24x7 as long as the DustIQ itself is dry. Supposedly, the MARS does not need dust calibration, but no proof has been published. Since the MARS only has one sensor it cannot show the soiling difference top to bottom and when two are used they will not have the run-off of soiling due to wind, rain and dew.

Q: Does DustIQ work independently or for all PV technologies, i.e. Bifacial PV?

A: It works for all silicon- based PV modules and also upside down for bifacial.

Q: What if there are different types of dust throughout the year?

A: The DustIQ has not been designed for that.

Q: Is there a plan to offer a traceable temperature sensor for the DustIQ?

A: This is under investigation.

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