EKO Beyond Accuracy.

MS-80 Secondary Standard Pyranometer "High-end for an industrial application"

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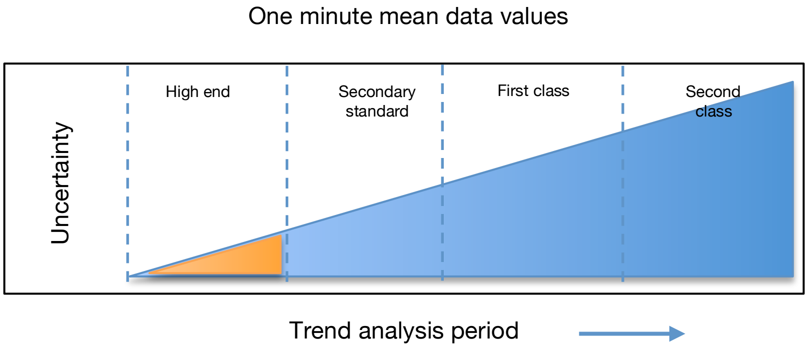
EKO's new generation ISO 9060 Secondary Standard sensor broke with the tradition of common pyranometer architecture and performance standards. The innovative design inspired by the latest detector and Quartz diffusor technologies enabling a breakthrough in unprecedented low thermal offset behaviour and fast thermopile response. The MS-80, ISO 9060 Secondary standard pyranometer developed for long term unattended outdoor operation to provide the lowest measurement uncertainties and best data availability under all atmospheric conditions when deployed in harsh environments.

High-end for industrial application

To obtain the most reliable Solar irradiance data at PV plants or meteorological stations, ISO 9060 Secondary Standard pyranometers are most commonly prescribed. These applications represent the beginning of the "high-end" applications for pyranometers. There are a variety of pyranometers in this category, some just comply with the ISO 9060 requirements and defined as an acceptable standard for PV monitoring applications. However, the best performing Secondary Standard pyranometers in this "high-end" range of pyranometers are rare and only used for very "high-end" research applications. The reason for their scarcity is their price is cost prohibitive for many applications.
Our aim was to develop an industrial sensor at a price that would allow for distributive networks while still realizing "high-end" specifications. This proliferation of "high-end" sensors will improve data quality and accuracy for regular PV monitoring applications and meteorological sensor networks. EKO's approach has resulted in a new generation secondary standard pyranometer, which provide the lowest measurement uncertainty. Better performance combined with an extended warranty and re-calibration interval period yield the lowest cost of ownership pyranometer on the market.

The advantage of a lower measurement uncertainty

What does a lower measurement uncertainty mean on a short or long time scale? Discerning short-term trends can only be detected with pyranometers capable of providing quality short-term data. Slower sensors cause longer time intervals between measurements. Larger measurement uncertainties decrease confidence in the claims made from the data. Confidence can be increased by applying statistics on an increasingly large data set. However, this dataset takes time to accrue. If important decisions must be made based on data taken over a short interval, a sensor with a fast response time, low measurement uncertainty, and a matching data-acquisition system are required.



Pyranometers with a slower response and greater measurement uncertainty can only be used to detect long-term trends, perhaps taking weeks or even months. As the measurement campaign continues for months or years, other important factors to take into account come into play. A primary consideration for such long-term applications require considerations of the long-term stability properties of a pyranometer. For PV monitoring applications, it is beneficial to detect short-term changes to maintain and guarantee PV system performance. To detect PV system performance changes of for example 2%, only pyranometers with a lower than 2% measurement uncertainty should be used. In case a pyranometer or reference sensor is applied with a greater measurement uncertainty, it will take more time and data to detect system performance losses.

Unique pyranometer architecture

Typical for the Secondary Standard thermopile pyranometers are the double domes, which are applied to improve the thermal balance of the sensor and to lower the offset characteristics. The “High-end” pyranometers have domes made of expensive Quartz or Sapphire to reduce the offset uncertainty and are most commonly used for top research specific applications. While the compact MS-80 sensor has only a single glass dome, through clever optical design it is immune to thermal offsets. Meaning, the performance of the MS-80 rivals the top competition while sold at a fraction of the cost. Without a second dome, the optics were designed to provide a true cosine response and flat spectral responsivity in the range 285nm – 3000nm. Furthermore, the isolated thermopile detector is hermetically sealed and accommodated deep inside the sensor body to keep it thermally balanced. The long-term detector responsivity is enhanced and is no longer affected by long-term exposure to UV irradiance, humidity, and pressure fluctuations. As a final plus, there is no longer the drying cartridge that needs to be checked regularly. The MS-80 contains the drying agent inside the sealed sensor body. There is no need for replacement.

Outstanding performance

EKO Instruments' test facilities are state of the art. Extensive indoor and outdoor tests were carried out to validate MS-80 sensor performance characteristics and to quantify the results. Specifications defined under ISO 9060 were verified primarily indoors. Whereas outdoor tests were performed to assess the measurement performance and uncertainty compared against competing secondary pyranometers. In addition the long-term stability characteristics were validated by independent test labs and research institutes.
The sensor characteristics and test results prove that the MS-80 sensor is not like any other traditional secondary standard pyranometers in the market. Test results appeared to be very consistent, given that traditional pyranometers generally have less consistency due to the detector construction and manufacturing process.

Specifications:

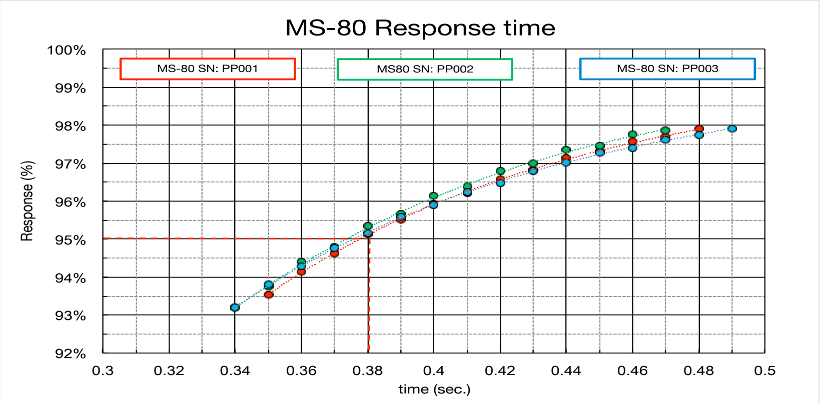
Characteristics	**MS-80**	**ISO 9060 Secondary - standard**
Response Time (95%)	<0.5 Sec	< 15 Sec
Zero Off-Set A (200W/m^2 IR)	< 1 W/m^2	< 7 W/m^2
Zero Off-Set B (5 K/h)	< 1 W/m^2	< 2 W/m^2
Long-Term Stability (1 year)	< 0.5 % (**5 years**)	< 0.8 %
Non-Linearity	< 0.2 %	< 0.5 %
Directional Response	< 10 W/m^2	< 10 W/m^2
Spectral Selectivity (300nm – 1,5µm)	< 3 %	< 3 %
Temperature Response (-20 to 50°C)	< 1 %	< 2 % (-10 to 40°C)
Tilt Response	< 0.2 %	< 0.5 %
Wavelength range	285 to 3000 nm	300 - 3000 nm

Test results

EKO sensors were extensively tested indoors and outdoors during and after the development process. The performance characteristics are based on the typical values as measured by multiple sensors.

Fastest detector response

The MS-80 has an analog thermopile providing a response time, which is only a fraction of second (99%). A fast detector is beneficial to stay perfectly in sync with rapid atmospheric changes. Data can be sampled at a higher frequency to minimize the measurement uncertainty for one minute or longer averaged values.



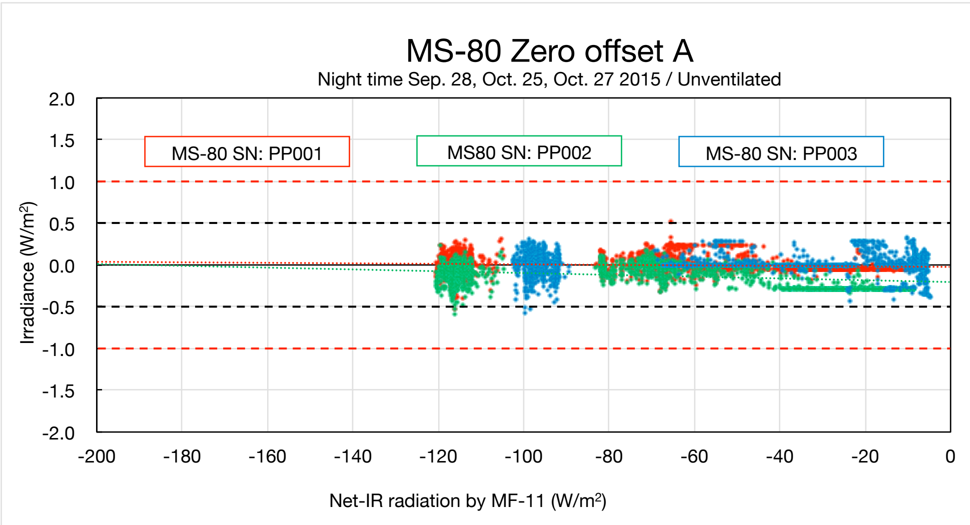
Measuring faster

Before the MS-80, EKO released the MS-56 pyrheliometer. These radiometers can sample much faster than previous versions. Faster sample rates allow the sensor to 'catch' more accurately the peak irradiance values in case of rapid atmospheric changes. Even on clear sky days the Solar irradiance seem to be constant on a minute scale. Due to atmospheric turbidity the irradiance can easily fluctuate by a few W/m^2. To detect sub-second changes, it is important to match the sampling rate of the data acquisition System with the sensor response time. As rule of thumb, the sampling time should be below the response time (t = 63%) of the sensor. Hence data reduction can be applied to store only minute values.

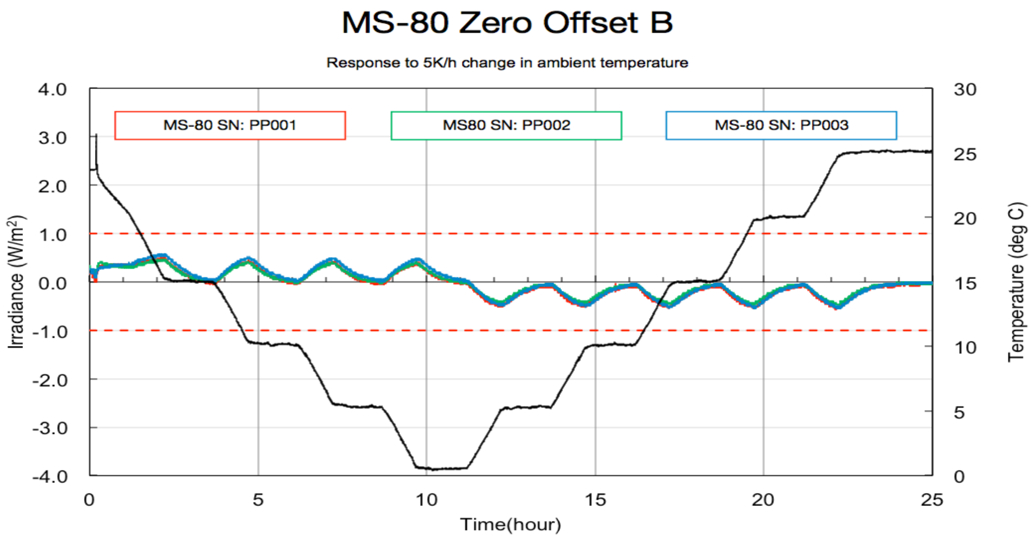
"Measuring faster", requires faster sampling of the data. When comparing sub-second sensors with traditional slower response sensors, the data acquisition system should be matched with the fastest sensor in the system. Under sampling conditions lead to substantial mismatch and anomalies when sensors with different time constant are compared with each other. Commonly when the data acquisition sampling time is set to 1s, it gives the impression that the fast sensor is instable. In contrary, it is the slower sensor smoothing the irregular pattern of the actual irradiance.

Lowest offsets

Offsets are a consequence of thermal differences between the optics (domes or diffusers) and detector, which are variable and influenced by conditional radiative and convective factors (Irradiance / Net-IR / Temperature / etc). In order to optimize the offset characteristics of a pyranometer, EKO changed the pyranometer architecture and geometry to eliminate temperature effects between the optics and detector. Generally, a smaller diameter dome, gives a lower heat loss and cooling effect compared to larger double dome concepts. In combination with the diffusor and isolated detector it can keep the MS-80 sensor in a proper thermal balance under varying atmospheric and environmental conditions. Zero offset A, known as the "dome cooling" effect is absent from the MS-80 and stays within the measurement uncertainty of 1 W/m^2 specified in the Net-IR range up to -200 W/m^2 (unventilated / ventilated).



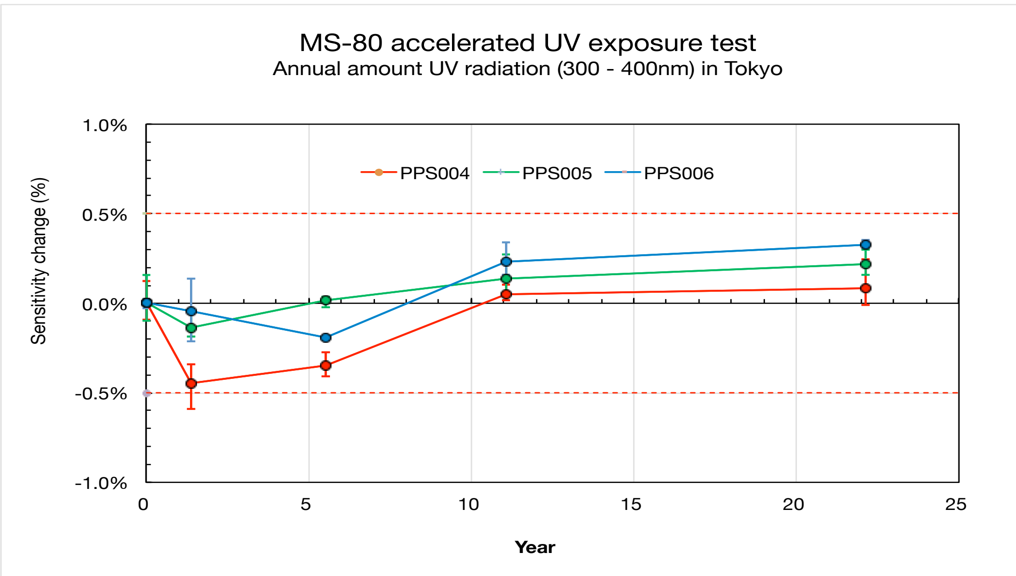
Zero offset B is defined as the detector response caused by a gradual change of ambient temperature or exposure to irradiance. The MS-80 typical zero offset B is <1W/m^2 / 5K per hour.



Long-term stability

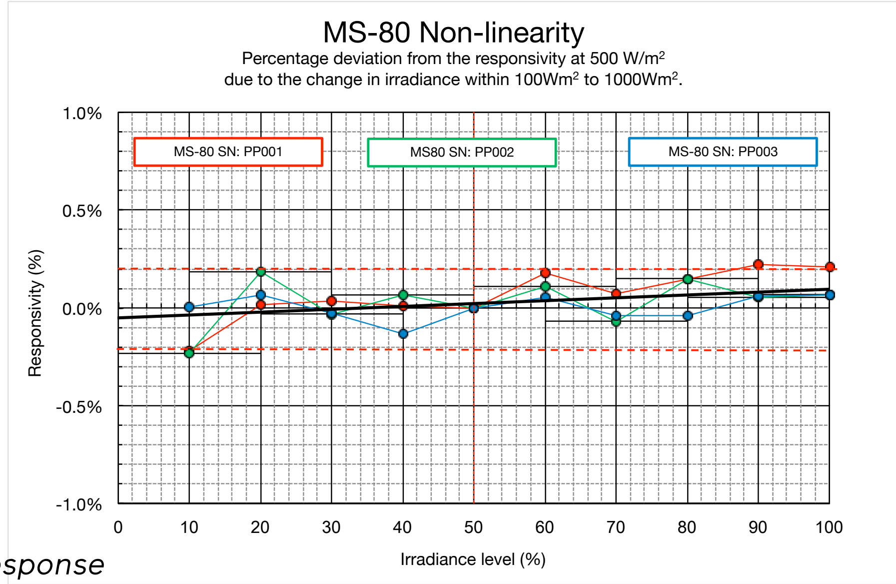
A third-party test lab performed an extensive UV stability test (JIS B7751 "Light-exposure and light-and-water-exposure apparatus) and thermal cycle test to simulate and validate the sensor performance over a long period of field operation. Results do not reveal any degradation of the detector responsivity over time larger than 0.5% taken into account the uncertainty of the measurement method.
Compared to all other pyranometers in the market the MS-80 has improved long-term stability properties. Therefore, the recommended period of recalibration can be extended to 5 years, which is typically 2 years for other sensor models in the market. The long-term stability of the sensor responsivity is less than 0.5% in a period of 5 years which makes it unique.

Based on the hermetically sealed construction and high quality sensor components also the standard warranty period is 5 years. MS-80 has no drying cartridge eliminating the need to replace the silicagel inside. All features that in combination make up the most cost effective pyranometer to date.



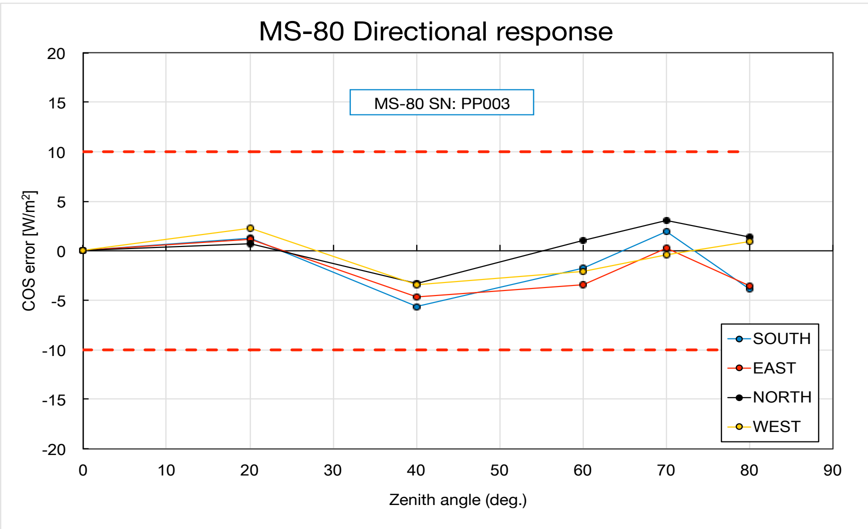
Non-linearity

The detector responsivity is proportional to irradiance with a measurement uncertainty of <0.2% in the range 100...1000 W/m^2. To quantify the results, EKO developed an accurate test method to verify the results indoors and outdoors.



Cosine response

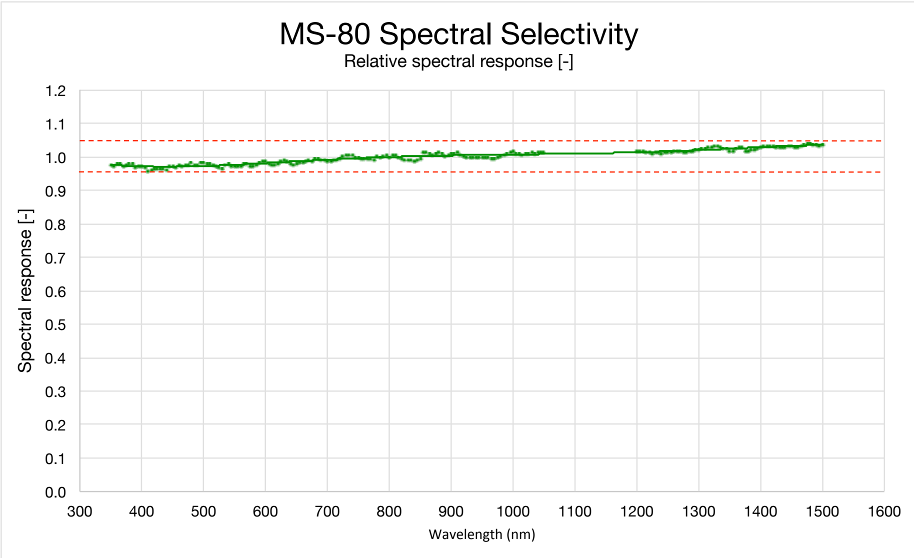
The single glass dome with diffusor is one of MS-80 unique aspects compared to other Secondary standards pyranometers in the market. It has a true cosine/azimuth response, which is plotted as deviation to the theoretical cosine response (W/m^2).



The cosine characteristics of each sensor will be tested for Solar zenith angles up to 80° in 4 different azimuth directions. A test report of each MS-80 is provided standard with every purchase.

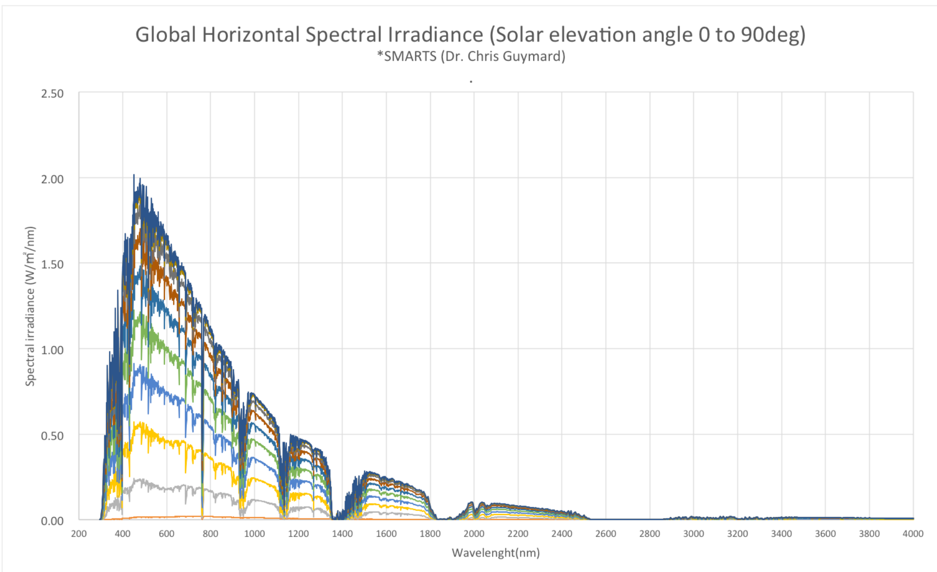
Spectral Selectivity

MS-80 has a thermopile detector and Quartz diffusor and is responsive to radiation within the full Solar spectral range. The spectral selectivity complies with ISO 9060 and defined as the percentage deviation of the product of spectral absorption and spectral transmittance from the corresponding mean within 350 nm and 1500nm. In the figure below the relative spectral response of MS-80 is plotted.

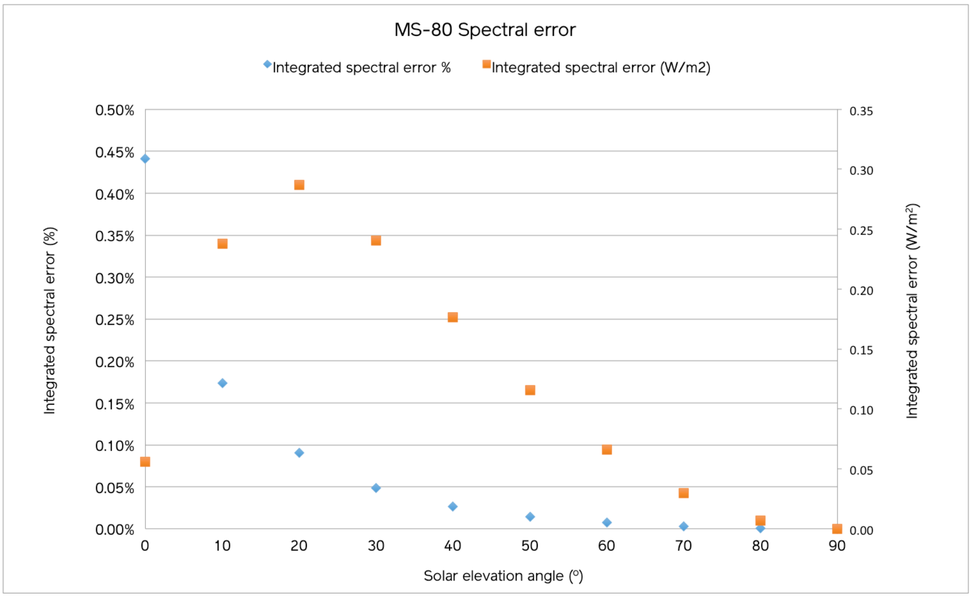


MS-80 Spectral selectivity

From the spectral response function the spectral error can be calculated within the Solar spectral range (295nm – 4000nm). The solar spectrum is not a constant, but will change with the path through the atmosphere as well as changing concentrations of atmospheric constituents. Hence the integrated spectral error was calculated as a function of airmass (AM1 to AM38) using the *SMARTS model (developed by Dr. Christian Guymard)*. The relative spectral errors and absolute errors are plotted as a function of the corresponding solar elevation angle corresponding to a calibration at the measurement condition AM1.5.



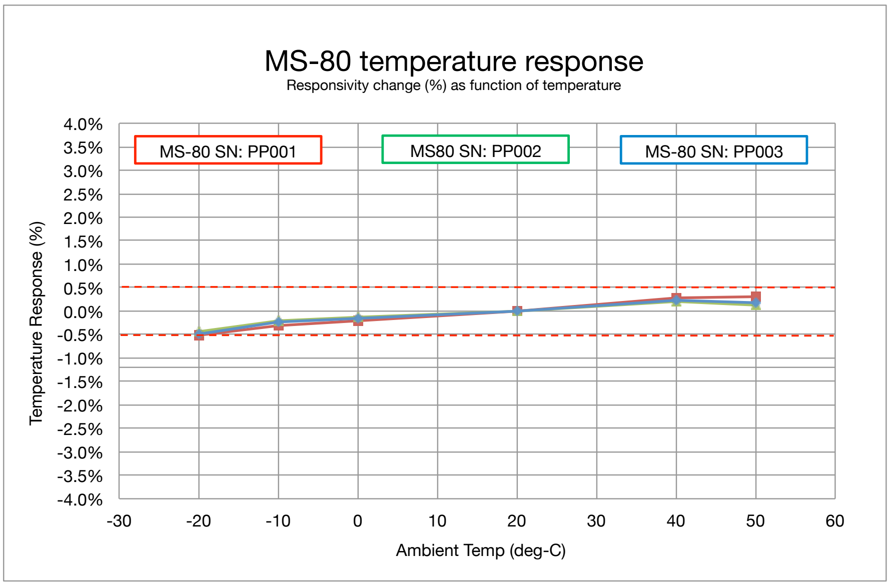
SMARTS spectra (AM1 – AM38)



MS-80 Spectral error

Low temperature coefficient

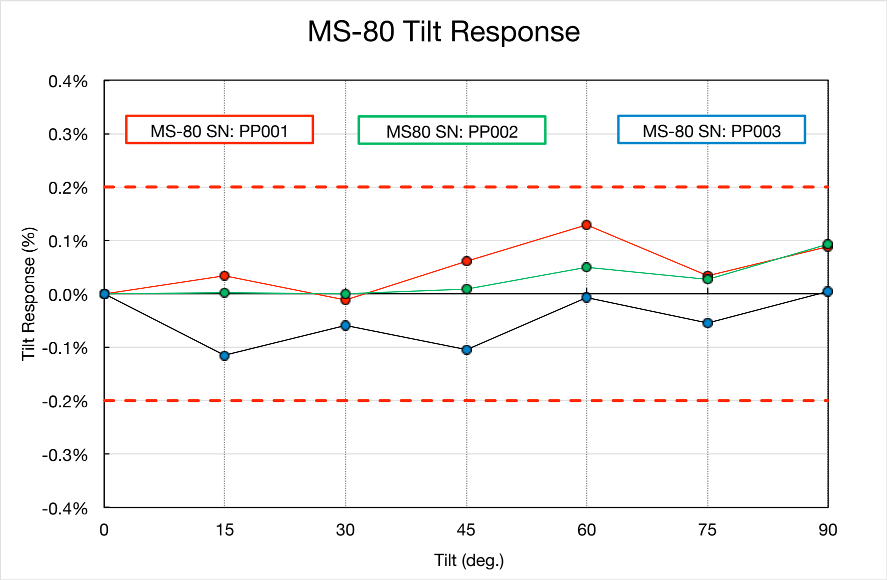
Due to the embedded analog temperature compensation electronics, the detector has a very low temperature coefficient. The MS-80 gives a linear output as a function of irradiance in a wide temperature range, without the need for data correction.



Temperature characteristics of each sensor are tested in the range -20°C to 50°C. A test report of each MS-80 is provided standard with every purchase.

Tilt response

Percentage deviation from the responsivity at 0° tilt (horizontal) due to change in tilt from 0° to 90° at 1000W/m^2 irradiance



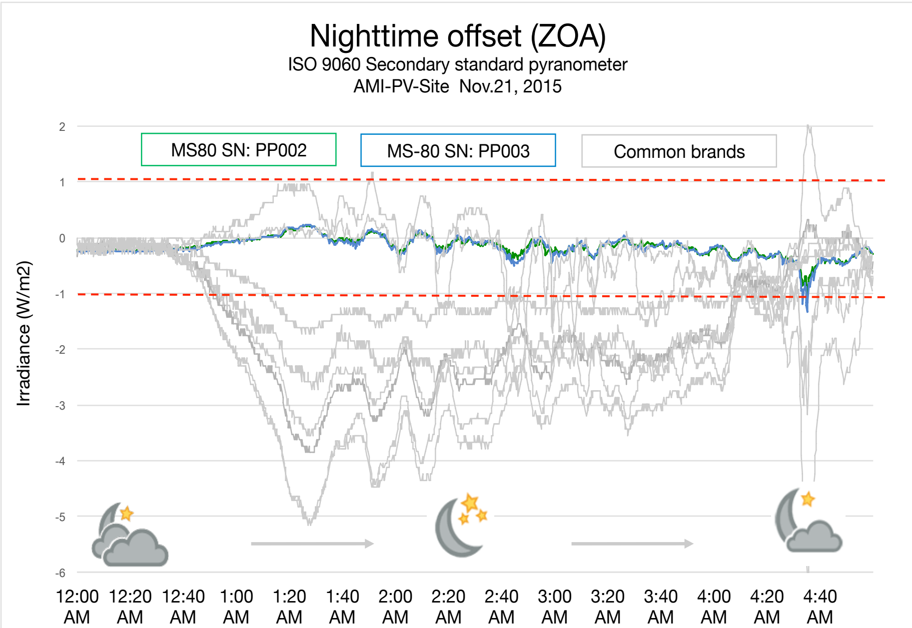
Outdoor performance

Observations of multiple MS-80 units with collocated secondary standard common brand pyranometers were made. In the setup global horizontal irradiance is measured.

The illustrative figures show the measurement results obtained for various days and night. Note the excellent agreement overall, MS-80 performance shows to be very consistent during variable atmospheric conditions at day- and nighttime.

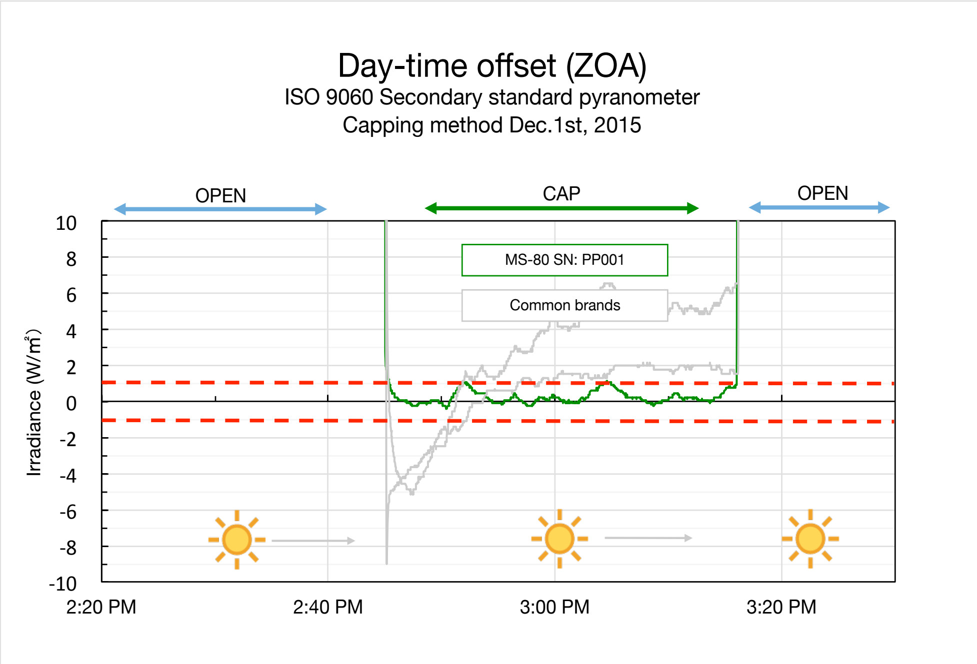
Nighttime offset

During nighttime, pyranometers tend to generate a negative output known as the zero offset A effect. Which is one of the error sources typically detected for conventional thermopile pyranometers. The nighttime offset is a clear performance indicator with respect to the detector thermal balance and sensor susceptibility to offsets. During overcast sky conditions, pyranometers offsets will be zero. However, for clear sky conditions the offset is proportional to the Net radiation-IR (W/m^2). The MS-80 shows very low offset values under all nighttime conditions.



Daytime offset

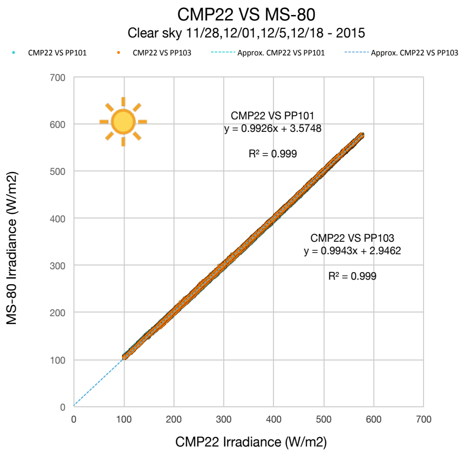
Pyranometer zero offsets usually get mixed with the irradiance signal and become indiscernible during daytime. During clear sky conditions, it usually leads to underestimation of the irradiance measurement. With the so-called “capping method” the hidden zero offset A can be revealed. In the plot below the MS-80 results show that zero offset are absent during day-time. Generally, zero offsets get larger due to the fact that the ambient temperature will increase and the sun will heat the sensor. A greater temperature difference will cause the IR net-radiation values to increase.

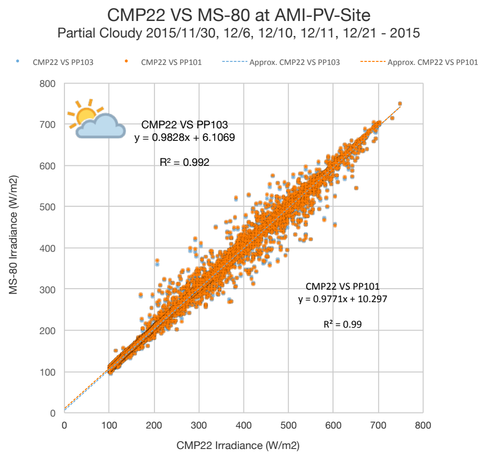


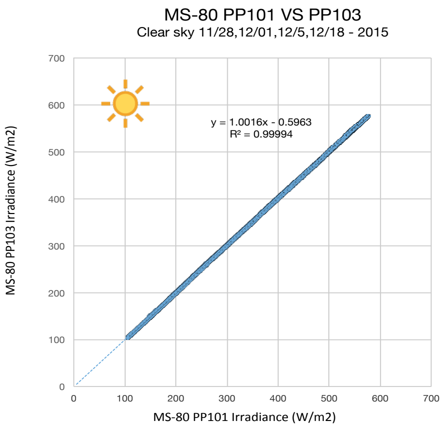
The low offset characteristics make the MS-80 pyranometer also highly suitable for diffuse radiation measurements. With clear or overcast skies the diffuse irradiance is just a fraction of the global irradiance. Hence the pyranometer offsets largely contribute to the measurement uncertainty. To measure diffuse irradiance in addition a Sun tracker with shading system is required.

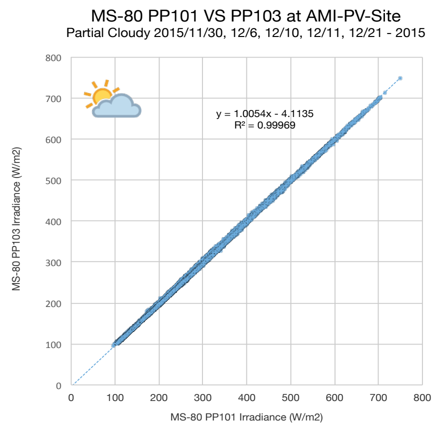
Irradiance measurements

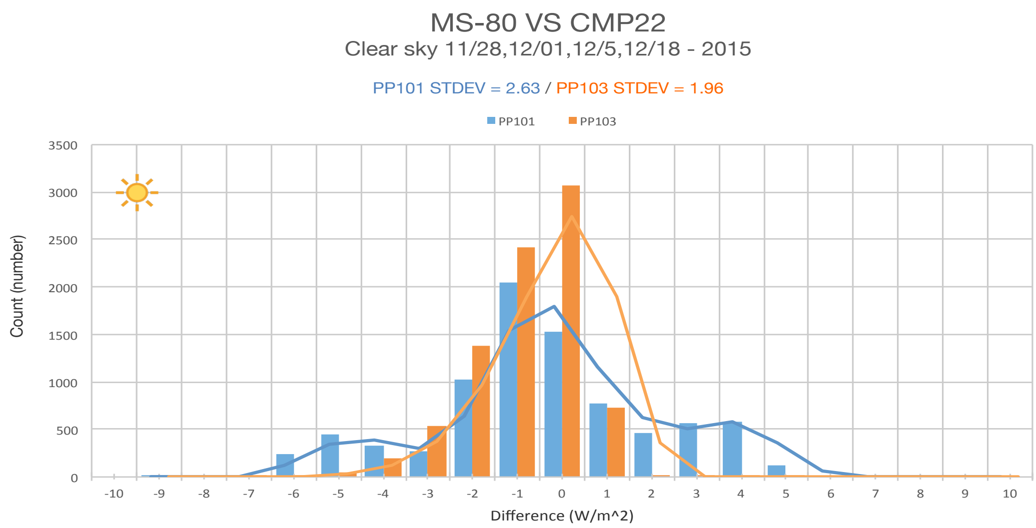
Irradiance data was measured every 10s and compared for various sky conditions, respectively clear sky and partly cloudy. The MS-80 pyranometer show excellent correlation for both conditions against a high-end pyranometer. During partial cloudy conditions a fast detector response time matters. The correlation coefficient between the two MS-80's is better.











Expanded measurement uncertainty

A brief look at the MS-80 specification list gives an impression of the many parameters that affect the radiation measurements. Fortunately, all these individual error sources, which have a small magnitude, will rarely affect the measurement at the same time. However, it is very difficult to calculate the combined measurement uncertainty because it is nearly impossible to isolate the individual measurement conditions to determine the corresponding errors. This illustrates the difficulty and complexity of the measurement uncertainty calculation. However, using the pyranometer specifications, an assessment can be made for the measurement uncertainty of ISO 9060 Secondary Standard pyranometers. For the analysis, several assumptions were made with respect to the individual specifications considering the measurement and calibration uncertainty and conditions. The specifications for the ISO9060 pyranometer classes are based on the specifications for a common brand model in the market. Generally, the sensor specifications are slightly better than the limiting specification defined by ISO 9060.

Table 1: Expanded uncertainty secondary standard pyranometers

	MS-80	High-end	Common brand	ISO 9060
Calibration accuracy* (%)	0.7	1.2	1.2	1.2
Zero offset A (W/m2)	1.0	3.0	7.0	7.0
Zero offset B (W/m2)	1.0	1.0	2.0	2.0
Non-Stability (%)	0.5	0.5	0.5	0.8
Non-linearity (%)	0.2	0.2	0.2	0.5
Directional response (W/m2)	10.0	5.0	10.0	10.0
Spectral selectivity** (%)	0.4	0.4	0.4	0.7
Temperature response*** (%)	0.5	0.5	1.0	1.0
Tilt response (%)	0.2	0.2	0.2	0.5
Expanded uncertainty (k=1.96)	1.6%	1.6%	2.3%	2.5%

*Calibration uncertainty commonly specified in the market (EKO Calibration uncertainty = 0.7% K=1.96) / **Effect of sensor spectral selectivity / ***Calibration reference temperature 20°C (-20°C to 50°C) / (Response time not accounted for)

The expanded measurement uncertainty associated with the ISO 9060 pyranometer class is calculated as the square root of the sum of the squares of the individual uncertainties and could be considered the worst case scenario.

Calibration

The MS-80 pyranometer is calibrated indoors against a calibrated MS-80 reference pyranometer using a solar simulator (1000 W/m² AM1.5 class AAA) as source (Method ISO 9847). The pyranometer is situated on a horizontal table and aligned to the optical axis of a normal incidence light source thus eliminating some of the sources of error mentioned above. By alternating the position of the calibrated reference pyranometer with the test pyranometer the output signal of both pyranometers are recorded and used to solve the equation of the unknown sensitivity variable. The operating conditions are maintained constant (e.g. ambient temperature and normal incidence irradiance), hence the pyranometer uncertainty figure is determined through summation in quadrature of the sensitivity uncertainty of the reference (Ur), uncertainty of temperature (Ut), repeatability (Ur) and normal distribution (d).

1) Uncertainty of reference (Ur)	0,31%
2) Uncertainty of temperature (Ut)	0,14%
3) Repeatability (Ur)	0,04%
4) Distribution (d)	0,03%
Total uncertainty (Uc)	0,34%
Expanded uncertainty (U)	0,69%

The expanded calibration uncertainty associated with the pyranometer sensitivity figure is calculated as the square root of the sum of the squares of the reported uncertainties: $1.96 \times \sqrt{(Ur^2 + Ut^2 + Ur^2 + d^2)}$

The MS-80 Secondary Standard pyranometer reference sensor is calibrated against the primary standard PMO-6 per the sun-and-shade method under ISO 9846. The primary standard is directly traceable to the World Radiometric Reference (WRR) and maintained in the group of standard radiometers calibrated every 5 years during the International Pyrheliometer Comparison (IPC). EKO also performs an annual calibration check of the reference instrument during the National Renewable Energy Laboratory (NREL) Pyrheliometric Comparison (NPC).
EKO Instruments Co. Ltd. calibration laboratory is accredited and certified by PJLA (Ref: **#74158**) to perform pyranometer and pyrheliometer calibrations in accordance with the requirements of ISO/IEC17025, which are relevant to calibration and testing.
EKO offer a unique manufacturer calibration service for pyranometers and pyrheliometers in-house. Based on the applied calibration methods EKO provides the best quality Solar sensor calibrations compliant to the international standards defined by ISO/IEC17025 / 9847 (Indoor method) and 9059 (Outdoor method), as defined by the scope of calibrations.
ISO/IEC17025 provides a globally accepted basis for laboratory accreditation that specifies the management and technical requirements.

With calibrations performed at the EKO Instruments laboratory we enable our customers to:

- Clearly identify the applied calibration methods and precision
- Be traceable to the World Radiation Reference (WRR) through defined industrial standards:
- ISO9846 Calibration of a pyranometer using a pyrheliometer
- ISO9847 Calibration of field pyranometer by comparison to a reference pyranometer
- ISO9059 Calibration of field pyrheliometers by comparison to a reference pyrheliometer
- Obtain repeatable and reliable calibration test results through consistent operations yearly examined independently to assure strict compliance to the requirements.

Our clients will obtain the highest level of confidence when purchasing an ISO/IEC17025 calibrated sensor. EKO's Accredited lab is regularly re-examined to ensure that they maintain their standards of technical as well as managerial expertise.

MS-80 market value

The MS-80 pyranometers combines all value-added functions such as the MV-01 ventilator, heater, and different industrial interfaces (4-20mA or MODBUS®).

The MS-80A is a MS-80 with built in 4-20mA converter, which is compatible to the industrial output standards. Due to the ultra-low temperature dependency and exceptional non-linearity characteristics, the converter guarantees an optimal sensor performance, under any environmental conditions. For easy conversion, the output is set to 4-20mA | 0 - 1600 W/m^2. With the optional USB controller and EKO Sense software, the converter settings can be freely changed. This tool will be needed in case the sensor sensitivity might need to be changed after a periodical Solar sensor re-calibration.

The MS-80M is a MS-80 with built in MODBUS® RTU 485 converter, which is compatible to the industrial output standards. As with the MS-80A, the ultra-low temperature dependency and non-linearity characteristics of the MS-80 guarantee an optimal synergy of performance between the sensor and converter resulting in uncompromised data quality under any environmental conditions. The MS-80M with MODBUS® converter can accommodate a local network of up to 100 different pyranometers and converter units. Each converter can be addressed and connected in parallel. The mV signal of the Solar sensor will be converted to irradiance between 0 - 1600 W/m^2. In this case, the sensitivity factor of the Solar sensor will be set to the converter. With the optional USB controller and EKO Sense software the converter settings can be freely changed. This tool will be needed in case the sensor sensitivity might need to be changed after a periodical Solar sensor re-calibration.
The MS-80 pyranometers are manufactured in a consistent way followed by strict quality inspection and performance evaluation. For each sensor, the directional response and temperature dependency are measured and validated through a measurement report that comes with the sensor. EKO provides a unique calibration compliant to the international standards defined by ISO/IEC17025 / 9847.
Versatile design coupled together with unique performance and stability characteristics make the MS-80 the most distinct pyranometer on the market. MS-80 detector architecture and new optical design can be clearly identified. Major performance gains have occurred in response time, long-term stability, and reduction of offsets. A new generation of pyranometers and a new chapter in pyranometer development are being written by EKO Instruments.

The combination of MS-80 with the compact MV-01 ventilator and heater makes that the forced air can be heated effectively and will keep the sensor dome and cover free of dew, fog, ice, and snow especially during severe winter conditions. The MS-80 offset characteristics will not change in combination with the MV-01 ventilator and heater. The 7W heater can heat up the air to 1-2°C above ambient temperature, which due to the offset immunity can only be done safely with the MS-80. The heater and ventilator are suggested, particularly over areas impacted by dew, frost, snow, and dust.

For any questions, please contact us at one of the EKO offices:

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