



## World Bank – Kenya

### Post Measurement Campaign Instrument Calibration Results

As part of the scope of this project GeoSUN was commissioned to calibrate the solar instruments after one year of measurement. Due to Covid-19 travel restrictions this was not possible and the calibration option changed to a post measurement campaign calibration. This entailed calibrating the instruments on decommissioning of the station and if any significant instrument drifts were observed the measured data would be post processed with adjusted multiplier.

The solar instrument calibration results per station are summarised in Table 1 to Table 3. Calibration certificates are provided in Appendix A. The calibration results showed no significant sensor drifts for any of the instruments.

*Table 1: Laisamis Calibration Results*

Instrument	Measurement	Make and Model	Serial Number	Calibration Multiplier (on installation)	Original Calibration Multiplier [ $\mu\text{V}/\text{W}/\text{m}^2$ ]	Original Calibration Date	Current Calibration Multiplier [ $\mu\text{V}/\text{W}/\text{m}^2$ ]	Calibration Date	Annual Sensor Drift Since Original Date
Pyranometer	GHI (1)	Hukseflux SR20-T2	7277	12.71	12.66	13-Jun-17	12.81	16-May-22	0.23%
Pyranometer	GHI (2)	Kipp & Zonen CMP11	127719	8.86	8.77	28-Aug-15	8.78	23-Mar-22	0.02%
Instrument	Measurement	Make and Model	Serial Number	Calibration Multiplier (on installation)	Original Calibration Multiplier	Original Calibration Date	Current Calibration Multiplier	Calibration Date	Error Before Recalibration
Pyranometer	DHI (1)	Delta-T Devices SPN1	A2007	1	1	28-Jun-19	1	23-Mar-22	3.6%

Table 2: Narok Calibration Results

Instrument	Measurement	Make and Model	Serial Number	Calibration Multiplier (on installation)	Original Calibration Multiplier [ $\mu\text{V}/\text{W}/\text{m}^2$ ]	Original Calibration Date	Current Calibration Multiplier [ $\mu\text{V}/\text{W}/\text{m}^2$ ]	Calibration Date	Annual Sensor Drift Since Original Date
Pyranometer	GHI (1)	Hukseflux SR20-T2	7276	13.26	13.24	19-Jun-17	13.33	25-Apr-22	0.14%
Pyranometer	GHI (2)	Kipp & Zonen CMP 11	128639	8.3	8.29	01-Nov-12	8.24	08-Mar-22	-0.06%
Instrument	Measurement	Make and Model	Serial Number	Calibration Multiplier (on installation)	Original Calibration Multiplier	Original Calibration Date	Current Calibration Multiplier	Calibration Date	Error Before Recalibration
Pyranometer	DHI (1)	Delta-T Devices SPN1	A1703	1	1	01-Jun-17	1	16-Mar-22	2.7%

Table 3: Homa Bay Calibration Results

Instrument	Measurement	Make and Model	Serial Number	Calibration Multiplier (on installation)	Original Calibration Multiplier [ $\mu\text{V}/\text{W}/\text{m}^2$ ]	Original Calibration Date	Current Calibration Multiplier [ $\mu\text{V}/\text{W}/\text{m}^2$ ]	Calibration Date	Annual Sensor Drift Since Original Date
Pyranometer	GHI (1)	Hukseflux SR20-T2	7201	13.18	13.21	09-Jun-17	13.30	16-May-22	0.14%
Pyranometer	GHI (2)	Kipp & Zonen CMP10	151400	9.02	9.00	13-Apr-15	8.92	07-Mar-22	-0.13%
Instrument	Measurement	Make and Model	Serial Number	Calibration Multiplier (on installation)	Original Calibration Multiplier	Original Calibration Date	Current Calibration Multiplier	Calibration Date	Error Before Recalibration
Pyranometer	DHI (1)	Delta-T Devices SPN1	A1701	1	1	01-Jun-17	1	16-Mar-22	3.2%

# Appendix A Calibration Certificate



**Pyranometer ISO 9847 Calibration**

Certificate Number: GSACA-2170

## Calibrated Instrument

Instrument: Pyranometer  
Manufacturer: Hukseflux  
Model: SR20-T2  
ISO 9060:1990 Class: Secondary Standard

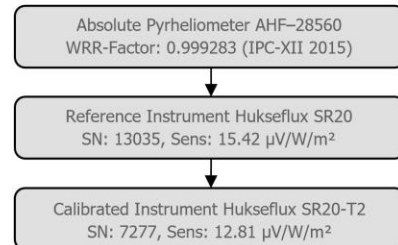
Calibration Date: 16 May 2022  
Serial Number: 7277  
New Sensitivity: 12.81  $\mu\text{V}/\text{W}/\text{m}^2$

## Calibration Methodology

GeoSUN performed an indoor calibration through exposure of both the calibrated instrument (instrument under test) and a reference instrument to an artificial light as radiation source and comparing the sensor outputs. The instruments were installed on a common horizontal base and regularly checked to ensure that it remained clean and level for the duration of the reference data being collected. The calibration was performed in accordance with the ISO 9847 (1992) standard, procedure type IIc.

## Reference Instrument and its Traceability

The reference instrument is a Hukseflux SR20 pyranometer (SN 13035). The instrument was calibrated on 8 March 2022 at ISO-CAL North America against absolute cavity radiometer AHF-28560 which successfully participated at IPC-XII 2015 with the World Standard Group of radiometers. The location of ISO-CAL is at 20th street, Phoenix, Arizona in the USA at latitude 33.8176944°, longitude -112.0396083° and altitude 570 m AMSL. The reference instrument was calibrated at normal incidence with the sun and sky radiation as the source using the "alternating sun-and-shade method". The readings are referenced to the World Radiometric Reference (WRR) as stated in the WMO Technical Regulations, originally with an SI relative uncertainty estimated at  $\pm 0.3\%$ . The diagram on the right shows the traceability hierarchy.



## Absolute Uncertainty

The absolute uncertainty is the combined result of three uncertainties namely:

- 1) The expanded uncertainty during calibration of the reference instrument, given as  $\pm 0.45\%$ .
- 2) The uncertainty in the correction of directional errors (cosine errors), estimated by scientific judgement as  $\pm 0.5\%$ .
- 3) The expanded uncertainty of the transfer procedure (calibration by comparison), estimated by scientific judgement as  $\pm 1\%$ .

The combined expanded uncertainty is the root sum of the squares, resulting in  $\sqrt{(0.45^2 + 0.5^2 + 1^2)} = \pm 1.21\%$ .

## Calibration Environment, Results and Instrument Status

The calibration was performed at latitude  $-33.96509^\circ$ , longitude  $18.84085^\circ$  and altitude 119 m AMSL and was concluded on 16 May 2022 at 16:01. A calibration was done using the measured output of the test instrument, of which the calibration environment and results are stated below. The measurement results recorded in this certificate were correct at the time of calibration. The subsequent accuracy will depend on factors such as care, handling and frequency of use. The calibration certificate or report may not be reproduced except in full, without the written approval of the laboratory.

### Instrument Status

Bubble Level: Good  
Dome: Good  
Desiccant: Replaced

### Calibration Environment - Average [Range]

Irradiation: 550 [549 - 550]  $\text{W}/\text{m}^2$   
Ambient Temperature: 25.3 [25.3 - 25.3]  $^\circ\text{C}$   
Reference Instrument Temp.: 25.4 [25.4 - 25.4]  $^\circ\text{C}$

### Original Calibration

Original Sensitivity: 12.66  $\mu\text{V}/\text{W}/\text{m}^2$   
Original Calib. Date: 13 June 2017

### Calibration Results

New Sensitivity: 12.80520  $\mu\text{V}/\text{W}/\text{m}^2$   
Sensitivity Standard Deviation ( $\sigma_{n-1}$ ): 0.00473  $\mu\text{V}/\text{W}/\text{m}^2$   
Calibration Uncertainty ( $k = 2$ ):  $\pm 0.1543 \mu\text{V}/\text{W}/\text{m}^2$  ( $\pm 1.21\%$ )  
Data Quantity : 4 Series, 16 Samples

Calibrated by:  
W.C. Engelbrecht

Authorised by:  
M.L. de Jager



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V2022/04/01  
Doc Date: 16 May 22  
End of certificate

# Calibration Certificate



**Pyranometer ISO 9847 Calibration**

Certificate Number: GSACA-2052

## Calibrated Instrument

Instrument: Pyranometer  
Manufacturer: Kipp & Zonen  
Model: CMP11  
ISO 9060:1990 Class: Secondary Standard

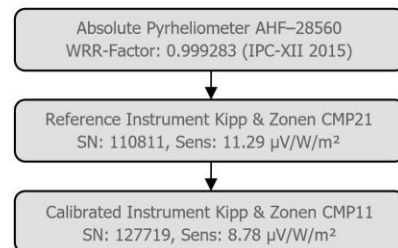
Calibration Date: 23 March 2022  
Serial Number: 127719  
New Sensitivity: 8.78  $\mu\text{V}/\text{W}/\text{m}^2$

## Calibration Methodology

GeoSUN performed an indoor calibration through exposure of both the calibrated instrument (instrument under test) and a reference instrument to an artificial light as radiation source and comparing the sensor outputs. The instruments were installed on a common horizontal base and regularly checked to ensure that it remained clean and level for the duration of the reference data being collected. The calibration was performed in accordance with the ISO 9847 (1992) standard, procedure type IIc.

## Reference Instrument and its Traceability

The reference instrument is a Kipp & Zonen CMP21 pyranometer (SN 110811). The instrument was calibrated on 29 December 2021 at ISO-CAL North America against absolute cavity radiometer AHF-28560 which successfully participated at IPC-XII 2015 with the World Standard Group of radiometers. The location of ISO-CAL is at 20th street, Phoenix, Arizona in the USA at latitude 33.8176944°, longitude -112.0396083° and altitude 570 m AMSL. The reference instrument was calibrated at normal incidence with the sun and sky radiation as the source using the "alternating sun-and-shade method". The readings are referenced to the World Radiometric Reference (WRR) as stated in the WMO Technical Regulations, originally with an SI relative uncertainty estimated at  $\pm 0.3\%$ . The diagram on the right shows the traceability hierarchy.



## Absolute Uncertainty

The absolute uncertainty is the combined result of three uncertainties namely:

- 1) The expanded uncertainty during calibration of the reference instrument, given as  $\pm 0.45\%$ .
- 2) The uncertainty in the correction of directional errors (cosine errors), estimated by scientific judgement as  $\pm 0.5\%$ .
- 3) The expanded uncertainty of the transfer procedure (calibration by comparison), estimated by scientific judgement as  $\pm 1\%$ .

The combined expanded uncertainty is the root sum of the squares, resulting in  $\sqrt{(0.45^2 + 0.5^2 + 1^2)} = \pm 1.21\%$ .

## Calibration Environment, Results and Instrument Status

The calibration was performed at latitude  $-33.96509^\circ$ , longitude  $18.84085^\circ$  and altitude 119 m AMSL and was concluded on 23 March 2022 at 12:32. A calibration was done using the measured output of the test instrument, of which the calibration environment and results are stated below. The measurement results recorded in this certificate were correct at the time of calibration. The subsequent accuracy will depend on factors such as care, handling and frequency of use. The calibration certificate or report may not be reproduced except in full, without the written approval of the laboratory.

### Instrument Status

Bubble Level: Good  
Dome: Abrasions present, Polished  
Desiccant: Replaced

### Calibration Environment - Average [Range]

Irradiation: 522 [520 - 528]  $\text{W}/\text{m}^2$   
Ambient Temperature: 25.4 [25.2 - 25.5]  $^\circ\text{C}$   
Reference Instrument Temp.: 26.3 [26.1 - 26.4]  $^\circ\text{C}$

### Original Calibration

Original Sensitivity: 8.77  $\mu\text{V}/\text{W}/\text{m}^2$   
Original Calib. Date: 28 August 2015

### Calibration Results

New Sensitivity: 8.77682  $\mu\text{V}/\text{W}/\text{m}^2$   
Sensitivity Standard Deviation ( $\sigma_{n-1}$ ): 0.00266  $\mu\text{V}/\text{W}/\text{m}^2$   
Calibration Uncertainty ( $k = 2$ ):  $\pm 0.1058 \mu\text{V}/\text{W}/\text{m}^2$  ( $\pm 1.21\%$ )  
Data Quantity: 4 Series, 16 Samples

Calibrated by:  
W.C. Engelbrecht

W.C. Engelbrecht

Authorised by:  
M.L. de Jager

M.L. de Jager



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End of certificate




Delta-T Devices Ltd

## SPN1 Sunshine Pyranometer

# Calibration Certificate

This is to certify that the Sunshine Pyranometer type SPN1 identified below has been calibrated in accordance with Delta-T Devices Ltd standard production procedures and conforms to the specifications as detailed.

Serial Number	SPN1 – A2007
Date	23/03/2022
Authorised Signature	 Jamie Patrick

We recommend that this instrument is recalibrated every 2 years.

### Traceability

The SPN1 is calibrated under a uniform light source which simulates the solar spectrum, against a transfer standard SPN1. The transfer standard is calibrated outdoors against a Kipp & Zonen CM21 secondary standard pyranometer (calibration traceable to the World Radiometric Reference), with solar tracker and shading disk for diffuse measurement.

### Accuracy, Total (Global) and Diffuse radiation

When correctly calibrated, the expected accuracy is given in the table below. The figures give 95% confidence limits, i.e. 95% of individual readings will be within the stated limits under normal climatic conditions.

Overall accuracy:	±5% daily integrals ±5% ±10 W.m <sup>-2</sup> hourly averages ±8% ±10 W.m <sup>-2</sup> individual readings
Range	0 to >2000 W.m <sup>-2</sup>
Analogue output sensitivity	1mV = 1 W.m <sup>-2</sup>



### Delta-T Devices Ltd

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# SPN1 Service and Recalibration Report

R8129

SPN1 Serial Number: A2007	Serviced by: Jamie Patrick	Date: 25/03/22
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## Inspection

*Inspect and clean... Condition, observations, actions taken*

**Dome** Good.

**Seal** Good.

**Shadow mask** Good.

**Bezel** Good.

**Diffusers** Good.

**Connectors** Good.

**Desiccant holder** Good.

**Desiccant** Replaced desiccant capsule. Supplied spare.

**Main o-ring seal** Good.

**General condition and observations** Good. Normal wear and tear.

## Recalibration

**Calibration date :** 23/03/2022

**Error before recalibration :** 3.6%

# Calibration Certificate



**Pyranometer ISO 9847 Calibration**

Certificate Number: GSACA-2134

## Calibrated Instrument

Instrument: Pyranometer  
Manufacturer: Hukseflux  
Model: SR20-T2  
ISO 9060:1990 Class: Secondary Standard

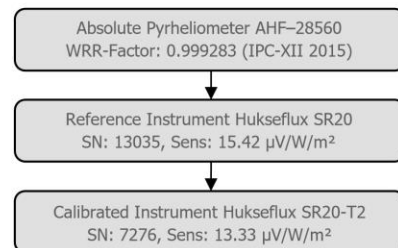
Calibration Date: 25 April 2022  
Serial Number: 7276  
New Sensitivity: 13.33  $\mu\text{V}/\text{W}/\text{m}^2$

## Calibration Methodology

GeoSUN performed an indoor calibration through exposure of both the calibrated instrument (instrument under test) and a reference instrument to an artificial light as radiation source and comparing the sensor outputs. The instruments were installed on a common horizontal base and regularly checked to ensure that it remained clean and level for the duration of the reference data being collected. The calibration was performed in accordance with the ISO 9847 (1992) standard, procedure type IIc.

## Reference Instrument and its Traceability

The reference instrument is a Hukseflux SR20 pyranometer (SN 13035). The instrument was calibrated on 8 March 2022 at ISO-CAL North America against absolute cavity radiometer AHF-28560 which successfully participated at IPC-XII 2015 with the World Standard Group of radiometers. The location of ISO-CAL is at 20th street, Phoenix, Arizona in the USA at latitude 33.8176944°, longitude -112.0396083° and altitude 570 m AMSL. The reference instrument was calibrated at normal incidence with the sun and sky radiation as the source using the "alternating sun-and-shade method". The readings are referenced to the World Radiometric Reference (WRR) as stated in the WMO Technical Regulations, originally with an SI relative uncertainty estimated at  $\pm 0.3\%$ . The diagram on the right shows the traceability hierarchy.



## Absolute Uncertainty

The absolute uncertainty is the combined result of three uncertainties namely:

- 1) The expanded uncertainty during calibration of the reference instrument, given as  $\pm 0.45\%$ .
- 2) The uncertainty in the correction of directional errors (cosine errors), estimated by scientific judgement as  $\pm 0.5\%$ .
- 3) The expanded uncertainty of the transfer procedure (calibration by comparison), estimated by scientific judgement as  $\pm 1\%$ .

The combined expanded uncertainty is the root sum of the squares, resulting in  $\sqrt{(0.45^2 + 0.5^2 + 1^2)} = \pm 1.21\%$ .

## Calibration Environment, Results and Instrument Status

The calibration was performed at latitude  $-33.96509^\circ$ , longitude  $18.84085^\circ$  and altitude 119 m AMSL and was concluded on 25 April 2022 at 09:20. A calibration was done using the measured output of the test instrument, of which the calibration environment and results are stated below. The measurement results recorded in this certificate were correct at the time of calibration. The subsequent accuracy will depend on factors such as care, handling and frequency of use. The calibration certificate or report may not be reproduced except in full, without the written approval of the laboratory.

### Instrument Status

Bubble Level: Good  
Dome: Good  
Desiccant: Good

### Calibration Environment - Average [Range]

Irradiation: 492 [492 - 493]  $\text{W}/\text{m}^2$   
Ambient Temperature: 20.7 [20.3 - 20.9]  $^\circ\text{C}$   
Reference Instrument Temp.: 20.4 [20.1 - 20.6]  $^\circ\text{C}$

### Original Calibration

Original Sensitivity: 13.24  $\mu\text{V}/\text{W}/\text{m}^2$   
Original Calib. Date: 19 June 2017

### Calibration Results

New Sensitivity: 13.33271  $\mu\text{V}/\text{W}/\text{m}^2$   
Sensitivity Standard Deviation ( $\sigma_{n-1}$ ): 0.00303  $\mu\text{V}/\text{W}/\text{m}^2$   
Calibration Uncertainty ( $k = 2$ ):  $\pm 0.1607 \mu\text{V}/\text{W}/\text{m}^2$  ( $\pm 1.21\%$ )  
Data Quantity: 4 Series, 16 Samples

Calibrated by:  
R. Venter

Authorised by:  
M.L. de Jager



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Doc Date: 25 Apr 22  
End of certificate

# Calibration Certificate



**Pyranometer ISO 9847 Calibration**

Certificate Number: GSACA-2053

## Calibrated Instrument

Instrument: Pyranometer  
Manufacturer: Kipp & Zonen  
Model: CMP11  
ISO 9060:1990 Class: Secondary Standard

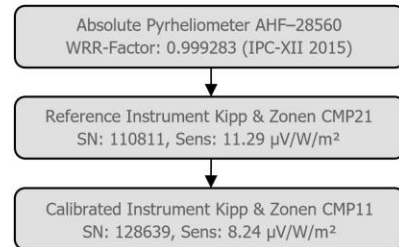
Calibration Date: 08 March 2022  
Serial Number: 128639  
New Sensitivity: 8.24  $\mu\text{V}/\text{W}/\text{m}^2$

## Calibration Methodology

GeoSUN performed an indoor calibration through exposure of both the calibrated instrument (instrument under test) and a reference instrument to an artificial light as radiation source and comparing the sensor outputs. The instruments were installed on a common horizontal base and regularly checked to ensure that it remained clean and level for the duration of the reference data being collected. The calibration was performed in accordance with the ISO 9847 (1992) standard, procedure type IIc.

## Reference Instrument and its Traceability

The reference instrument is a Kipp & Zonen CMP21 pyranometer (SN 110811). The instrument was calibrated on 29 December 2021 at ISO-CAL North America against absolute cavity radiometer AHF-28560 which successfully participated at IPC-XII 2015 with the World Standard Group of radiometers. The location of ISO-CAL is at 20th street, Phoenix, Arizona in the USA at latitude 33.8176944°, longitude -112.0396083° and altitude 570 m AMSL. The reference instrument was calibrated at normal incidence with the sun and sky radiation as the source using the "alternating sun-and-shade method". The readings are referenced to the World Radiometric Reference (WRR) as stated in the WMO Technical Regulations, originally with an SI relative uncertainty estimated at  $\pm 0.3\%$ . The diagram on the right shows the traceability hierarchy.



## Absolute Uncertainty

The absolute uncertainty is the combined result of three uncertainties namely:

- 1) The expanded uncertainty during calibration of the reference instrument, given as  $\pm 0.45\%$ .
- 2) The uncertainty in the correction of directional errors (cosine errors), estimated by scientific judgement as  $\pm 0.5\%$ .
- 3) The expanded uncertainty of the transfer procedure (calibration by comparison), estimated by scientific judgement as  $\pm 1\%$ .

The combined expanded uncertainty is the root sum of the squares, resulting in  $\sqrt{(0.45^2 + 0.5^2 + 1^2)} = \pm 1.21\%$ .

## Calibration Environment, Results and Instrument Status

The calibration was performed at latitude  $-33.96509^\circ$ , longitude  $18.84085^\circ$  and altitude 119 m AMSL and was concluded on 08 March 2022 at 08:45. A calibration was done using the measured output of the test instrument, of which the calibration environment and results are stated below. The measurement results recorded in this certificate were correct at the time of calibration. The subsequent accuracy will depend on factors such as care, handling and frequency of use. The calibration certificate or report may not be reproduced except in full, without the written approval of the laboratory.

### Instrument Status

Bubble Level: Good  
Dome: Good  
Desiccant: Replaced

### Calibration Environment - Average [Range]

Irradiation: 564 [563 - 565]  $\text{W}/\text{m}^2$   
Ambient Temperature: 24.9 [24.8 - 25.0]  $^\circ\text{C}$   
Reference Instrument Temp.: 25.5 [25.4 - 25.6]  $^\circ\text{C}$

### Original Calibration

Original Sensitivity: 8.29  $\mu\text{V}/\text{W}/\text{m}^2$   
Original Calib. Date: 01 November 2012

### Calibration Results

New Sensitivity: 8.23509  $\mu\text{V}/\text{W}/\text{m}^2$   
Sensitivity Standard Deviation ( $\sigma_{n-1}$ ): 0.00213  $\mu\text{V}/\text{W}/\text{m}^2$   
Calibration Uncertainty ( $k = 2$ ):  $\pm 0.0992 \mu\text{V}/\text{W}/\text{m}^2$  ( $\pm 1.21\%$ )  
Data Quantity: 4 Series, 16 Samples

Calibrated by:  
W.C. Engelbrecht

W.C. Engelbrecht

Authorised by:  
M.L. de Jager

M.L. de Jager



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End of certificate






Delta-T Devices Ltd

## SPN1 Sunshine Pyranometer

# Calibration Certificate

This is to certify that the Sunshine Pyranometer type SPN1 identified below has been calibrated in accordance with Delta-T Devices Ltd standard production procedures and conforms to the specifications as detailed.

Serial Number	SPN1 – A1703
Date	16/03/2022
Authorised Signature	 Jamie Patrick

We recommend that this instrument is recalibrated every 2 years.

### Traceability

The SPN1 is calibrated under a uniform light source which simulates the solar spectrum, against a transfer standard SPN1. The transfer standard is calibrated outdoors against a Kipp & Zonen CM21 secondary standard pyranometer (calibration traceable to the World Radiometric Reference), with solar tracker and shading disk for diffuse measurement.

### Accuracy, Total (Global) and Diffuse radiation

When correctly calibrated, the expected accuracy is given in the table below. The figures give 95% confidence limits, i.e. 95% of individual readings will be within the stated limits under normal climatic conditions.

Overall accuracy:	±5% daily integrals ±5% ±10 W.m <sup>-2</sup> hourly averages ±8% ±10 W.m <sup>-2</sup> individual readings
Range	0 to >2000 W.m <sup>-2</sup>
Analogue output sensitivity	1mV = 1 W.m <sup>-2</sup>



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# SPN1 Service and Recalibration Report

R8129

SPN1 Serial Number: A1703	Serviced by: Jamie Patrick	Date: 25/03/22
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## Inspection

*Inspect and clean... Condition, observations, actions taken*

**Dome** Good.

**Seal** Good.

**Shadow mask** Good.

**Bezel** Good.

**Diffusers** Good.

**Connectors** Good.

**Desiccant holder** Good.

**Desiccant** Replaced desiccant capsule. Supplied spare.

**Main o-ring seal** Good.

**General condition and observations** Good. Normal wear and tear.

## Recalibration

**Calibration date :** 16/03/2022

**Error before recalibration :** 2.7%

# Calibration Certificate



**Pyranometer ISO 9847 Calibration**

Certificate Number: GSACA-2169

## Calibrated Instrument

Instrument: Pyranometer  
Manufacturer: Hukseflux  
Model: SR20-T2  
ISO 9060:1990 Class: Secondary Standard

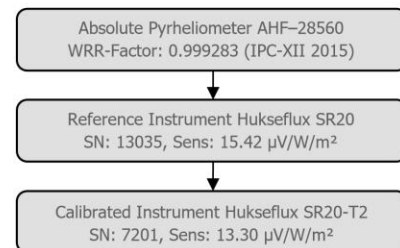
Calibration Date: 16 May 2022  
Serial Number: 7201  
New Sensitivity: 13.30  $\mu\text{V}/\text{W}/\text{m}^2$

## Calibration Methodology

GeoSUN performed an indoor calibration through exposure of both the calibrated instrument (instrument under test) and a reference instrument to an artificial light as radiation source and comparing the sensor outputs. The instruments were installed on a common horizontal base and regularly checked to ensure that it remained clean and level for the duration of the reference data being collected. The calibration was performed in accordance with the ISO 9847 (1992) standard, procedure type IIc.

## Reference Instrument and its Traceability

The reference instrument is a Hukseflux SR20 pyranometer (SN 13035). The instrument was calibrated on 8 March 2022 at ISO-CAL North America against absolute cavity radiometer AHF-28560 which successfully participated at IPC-XII 2015 with the World Standard Group of radiometers. The location of ISO-CAL is at 20th street, Phoenix, Arizona in the USA at latitude 33.8176944°, longitude -112.0396083° and altitude 570 m AMSL. The reference instrument was calibrated at normal incidence with the sun and sky radiation as the source using the "alternating sun-and-shade method". The readings are referenced to the World Radiometric Reference (WRR) as stated in the WMO Technical Regulations, originally with an SI relative uncertainty estimated at  $\pm 0.3\%$ . The diagram on the right shows the traceability hierarchy.



## Absolute Uncertainty

The absolute uncertainty is the combined result of three uncertainties namely:

- 1) The expanded uncertainty during calibration of the reference instrument, given as  $\pm 0.45\%$ .
- 2) The uncertainty in the correction of directional errors (cosine errors), estimated by scientific judgement as  $\pm 0.5\%$ .
- 3) The expanded uncertainty of the transfer procedure (calibration by comparison), estimated by scientific judgement as  $\pm 1\%$ .

The combined expanded uncertainty is the root sum of the squares, resulting in  $\sqrt{(0.45^2 + 0.5^2 + 1^2)} = \pm 1.21\%$ .

## Calibration Environment, Results and Instrument Status

The calibration was performed at latitude  $-33.96509^\circ$ , longitude  $18.84085^\circ$  and altitude 119 m AMSL and was concluded on 16 May 2022 at 15:32. A calibration was done using the measured output of the test instrument, of which the calibration environment and results are stated below. The measurement results recorded in this certificate were correct at the time of calibration. The subsequent accuracy will depend on factors such as care, handling and frequency of use. The calibration certificate or report may not be reproduced except in full, without the written approval of the laboratory.

### Instrument Status

Bubble Level: Good  
Dome: Good  
Desiccant: Replaced

### Calibration Environment - Average [Range]

Irradiation: 549 [549 - 550]  $\text{W}/\text{m}^2$   
Ambient Temperature: 25.0 [24.9 - 25.2]  $^\circ\text{C}$   
Reference Instrument Temp.: 25.2 [25.2 - 25.2]  $^\circ\text{C}$

### Original Calibration

Original Sensitivity: 13.21  $\mu\text{V}/\text{W}/\text{m}^2$   
Original Calib. Date: 09 June 2017

### Calibration Results

New Sensitivity: 13.30451  $\mu\text{V}/\text{W}/\text{m}^2$   
Sensitivity Standard Deviation ( $\sigma_{n-1}$ ): 0.00235  $\mu\text{V}/\text{W}/\text{m}^2$   
Calibration Uncertainty ( $k = 2$ ):  $\pm 0.1603 \mu\text{V}/\text{W}/\text{m}^2$  ( $\pm 1.21\%$ )  
Data Quantity : 4 Series, 16 Samples

Calibrated by:  
W.C. Engelbrecht

W.C.Engelbrecht

Authorised by:  
M.L. de Jager

M.L.deJager



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V2022/04/01  
Doc Date: 16 May 22  
End of certificate

# Calibration Certificate



**Pyranometer ISO 9847 Calibration**

Certificate Number: GSACA-2046

## Calibrated Instrument

Instrument: Pyranometer  
Manufacturer: Kipp & Zonen  
Model: CMP10  
ISO 9060:1990 Class: Secondary Standard

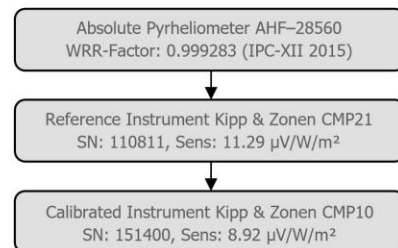
Calibration Date: 07 March 2022  
Serial Number: 151400  
New Sensitivity: 8.92  $\mu\text{V}/\text{W}/\text{m}^2$

## Calibration Methodology

GeoSUN performed an indoor calibration through exposure of both the calibrated instrument (instrument under test) and a reference instrument to an artificial light as radiation source and comparing the sensor outputs. The instruments were installed on a common horizontal base and regularly checked to ensure that it remained clean and level for the duration of the reference data being collected. The calibration was performed in accordance with the ISO 9847 (1992) standard, procedure type IIc.

## Reference Instrument and its Traceability

The reference instrument is a Kipp & Zonen CMP21 pyranometer (SN 110811). The instrument was calibrated on 29 December 2021 at ISO-CAL North America against absolute cavity radiometer AHF-28560 which successfully participated at IPC-XII 2015 with the World Standard Group of radiometers. The location of ISO-CAL is at 20th street, Phoenix, Arizona in the USA at latitude 33.8176944°, longitude -112.0396083° and altitude 570 m AMSL. The reference instrument was calibrated at normal incidence with the sun and sky radiation as the source using the "alternating sun-and-shade method". The readings are referenced to the World Radiometric Reference (WRR) as stated in the WMO Technical Regulations, originally with an SI relative uncertainty estimated at  $\pm 0.3\%$ . The diagram on the right shows the traceability hierarchy.



## Absolute Uncertainty

The absolute uncertainty is the combined result of three uncertainties namely:

- 1) The expanded uncertainty during calibration of the reference instrument, given as  $\pm 0.45\%$ .
- 2) The uncertainty in the correction of directional errors (cosine errors), estimated by scientific judgement as  $\pm 0.5\%$ .
- 3) The expanded uncertainty of the transfer procedure (calibration by comparison), estimated by scientific judgement as  $\pm 1\%$ .

The combined expanded uncertainty is the root sum of the squares, resulting in  $\sqrt{(0.45^2 + 0.5^2 + 1^2)} = \pm 1.21\%$ .

## Calibration Environment, Results and Instrument Status

The calibration was performed at latitude  $-33.96509^\circ$ , longitude  $18.84085^\circ$  and altitude 119 m AMSL and was concluded on 07 March 2022 at 14:50. A calibration was done using the measured output of the test instrument, of which the calibration environment and results are stated below. The measurement results recorded in this certificate were correct at the time of calibration. The subsequent accuracy will depend on factors such as care, handling and frequency of use. The calibration certificate or report may not be reproduced except in full, without the written approval of the laboratory.

### Instrument Status

Bubble Level: Good  
Dome: Good

### Calibration Environment - Average [Range]

Irradiation: 566 [565 - 566]  $\text{W}/\text{m}^2$   
Ambient Temperature: 23.7 [23.7 - 23.8]  $^\circ\text{C}$   
Reference Instrument Temp.: 24.5 [24.3 - 24.7]  $^\circ\text{C}$

### Original Calibration

Original Sensitivity: 9.00  $\mu\text{V}/\text{W}/\text{m}^2$   
Original Calib. Date: 13 April 2015

### Calibration Results

New Sensitivity: 8.91717  $\mu\text{V}/\text{W}/\text{m}^2$   
Sensitivity Standard Deviation ( $\sigma_{n-1}$ ): 0.00135  $\mu\text{V}/\text{W}/\text{m}^2$   
Calibration Uncertainty ( $k = 2$ ):  $\pm 0.1075 \mu\text{V}/\text{W}/\text{m}^2$  ( $\pm 1.21\%$ )  
Data Quantity : 4 Series, 16 Samples

Calibrated by:  
W.C. Engelbrecht

W.C.Engelbrecht

Authorised by:  
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Delta-T Devices Ltd

## SPN1 Sunshine Pyranometer

# Calibration Certificate

This is to certify that the Sunshine Pyranometer type SPN1 identified below has been calibrated in accordance with Delta-T Devices Ltd standard production procedures and conforms to the specifications as detailed.

Serial Number	SPN1 – A1701
Date	16/03/2022
Authorised Signature	 Jamie Patrick

We recommend that this instrument is recalibrated every 2 years.

### Traceability

The SPN1 is calibrated under a uniform light source which simulates the solar spectrum, against a transfer standard SPN1. The transfer standard is calibrated outdoors against a Kipp & Zonen CM21 secondary standard pyranometer (calibration traceable to the World Radiometric Reference), with solar tracker and shading disk for diffuse measurement.

### Accuracy, Total (Global) and Diffuse radiation

When correctly calibrated, the expected accuracy is given in the table below. The figures give 95% confidence limits, i.e. 95% of individual readings will be within the stated limits under normal climatic conditions.

Overall accuracy:	±5% daily integrals ±5% ±10 W.m <sup>-2</sup> hourly averages ±8% ±10 W.m <sup>-2</sup> individual readings
Range	0 to >2000 W.m <sup>-2</sup>
Analogue output sensitivity	1mV = 1 W.m <sup>-2</sup>



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# SPN1 Service and Recalibration Report

R8129

SPN1 Serial Number: A1701	Serviced by: Jamie Patrick	Date: 25/03/22
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## Inspection

*Inspect and clean... Condition, observations, actions taken*

**Dome** Good.

**Seal** Good.

**Shadow mask** Good.

**Bezel** Good.

**Diffusers** Good.

**Connectors** Good.

**Desiccant holder** Good.

**Desiccant** Replaced desiccant capsule. Supplied spare.

**Main o-ring seal** Good.

**General condition and observations** Good. Normal wear and tear.

## Recalibration

**Calibration date :** 16/03/2022

**Error before recalibration :** 3.2%