



World Bank – Uganda

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 and Table 2. Calibration certificates are provided in Appendix A. The calibration results showed no significant sensor drifts for any of the instruments.

Table 1: Soroti 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 Installation Date |
|-------------|-------------|----------------------|---------------|--|---|---------------------------|--|------------------|---|
| Pyranometer | GHI (1) | Kipp & Zonen CMP 10 | 163400 | 8.83 | 9.02 | 06-Dec-16 | 8.92 | 08-Mar-22 | -0.19% |
| Pyranometer | GHI (2) | Kipp & Zonen CMP 10 | 163401 | 9.55 | 9.72 | 06-Dec-16 | 9.71 | 16-May-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 | A2060 | 1 | 1 | 24-Sep-19 | 1 | 23-Mar-22 | 1.90% |

Table 2: Wadelai 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 Installation Date |
|-------------|-------------|----------------------|---------------|--|---|---------------------------|--|------------------|---|
| Pyranometer | GHI (1) | Kipp & Zonen CMP 10 | 140513 | 9.37 | 9.29 | 23-Apr-14 | 9.36 | 07-Mar-22 | 0.09% |
| Pyranometer | GHI (2) | Kipp & Zonen CMP 10 | 151711 | 8.05 | 8.04 | 28-Aug-15 | 8.05 | 07-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 | A2063 | 1 | 1 | 24-Sep-19 | Replaced with SPN1 (SN: A1091) on 17 Jul 2020 | | |
| Pyranometer | DHI (1) | Delta-T Devices SPN1 | A1091 | 1 | 1 | 15-Feb-18 | 1 | 16-Mar-22 | 2.4% |

Appendix A Calibration Certificate



Pyranometer ISO 9847 Calibration

Certificate Number: GSACA-2050

Calibrated Instrument

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

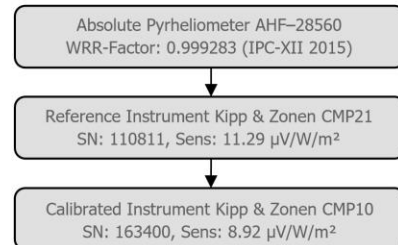
Calibration Date: 08 March 2022
Serial Number: 163400
New Sensitivity: 8.92 $\mu\text{V}/\text{W}/\text{m}^2$

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° , longitude 18.84085° and altitude 119 m AMSL and was concluded on 08 March 2022 at 07:48. 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: 564 [563 - 565] W/m^2
Ambient Temperature: 25.3 [25.2 - 25.5] $^\circ\text{C}$
Reference Instrument Temp.: 25.1 [24.3 - 25.4] $^\circ\text{C}$

Original Calibration

Original Sensitivity: 9.02 $\mu\text{V}/\text{W}/\text{m}^2$
Original Calib. Date: 06 December 2016

Calibration Results

New Sensitivity: 8.91898 $\mu\text{V}/\text{W}/\text{m}^2$
Sensitivity Standard Deviation (σ_{n-1}): 0.00156 $\mu\text{V}/\text{W}/\text{m}^2$
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

Authorised by:
M.L. de Jager



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Doc Date: 08 Mar 22
End of certificate

Calibration Certificate



Pyranometer ISO 9847 Calibration

Certificate Number: GSACA-2167

Calibrated Instrument

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

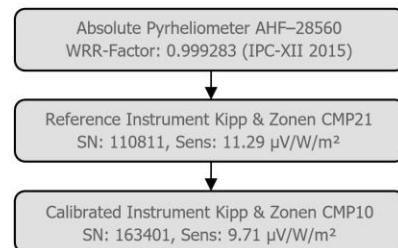
Calibration Date: 16 May 2022
Serial Number: 163401
New Sensitivity: 9.71 $\mu\text{V}/\text{W}/\text{m}^2$

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° , longitude 18.84085° and altitude 119 m AMSL and was concluded on 16 May 2022 at 12:14. 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: Dry, needs replacing
Dome: Good

Calibration Environment - Average [Range]

Irradiation: 568 [567 - 569] W/m^2
Ambient Temperature: 24.2 [24.0 - 24.4] $^\circ\text{C}$
Reference Instrument Temp.: 24.0 [23.7 - 24.3] $^\circ\text{C}$

Original Calibration

Original Sensitivity: 9.72 $\mu\text{V}/\text{W}/\text{m}^2$
Original Calib. Date: 06 December 2016

Calibration Results

New Sensitivity: 9.70538 $\mu\text{V}/\text{W}/\text{m}^2$
Sensitivity Standard Deviation (σ_{n-1}): 0.00111 $\mu\text{V}/\text{W}/\text{m}^2$
Calibration Uncertainty ($k = 2$): $\pm 0.117 \mu\text{V}/\text{W}/\text{m}^2$ ($\pm 1.21\%$)
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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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 – A2060 |
| 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 ⁻² hourly averages ±8% ±10 W.m ⁻² individual readings |
| Range | 0 to >2000 W.m ⁻² |
| Analogue output sensitivity | 1mV = 1 W.m ⁻² |



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SPN1 Service and Recalibration Report

R8129

| | | |
|---------------------------|----------------------------|----------------|
| SPN1 Serial Number: A2060 | Serviced by: Jamie Patrick | Date: 25/03/22 |
|---------------------------|----------------------------|----------------|

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 : 1.9%

Calibration Certificate



Pyranometer ISO 9847 Calibration

Certificate Number: GSACA-2043

Calibrated Instrument

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

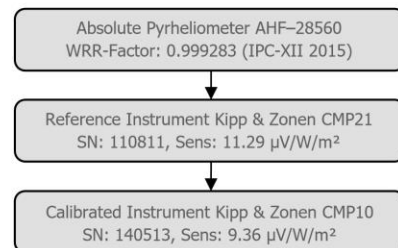
Calibration Date: 07 March 2022
Serial Number: 140513
New Sensitivity: 9.36 $\mu\text{V}/\text{W}/\text{m}^2$

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° , longitude 18.84085° and altitude 119 m AMSL and was concluded on 07 March 2022 at 12:26. 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: Enlarged but functional
Dome: Good

Calibration Environment - Average [Range]

Irradiation: 568 [567 - 569] W/m^2
Ambient Temperature: 24.7 [24.4 - 24.9] $^\circ\text{C}$
Reference Instrument Temp.: 25.3 [24.7 - 25.8] $^\circ\text{C}$

Original Calibration

Original Sensitivity: 9.29 $\mu\text{V}/\text{W}/\text{m}^2$
Original Calib. Date: 23 April 2014

Calibration Results

New Sensitivity: 9.35913 $\mu\text{V}/\text{W}/\text{m}^2$
Sensitivity Standard Deviation (σ_{n-1}): 0.00333 $\mu\text{V}/\text{W}/\text{m}^2$
Calibration Uncertainty ($k = 2$): $\pm 0.1128 \mu\text{V}/\text{W}/\text{m}^2$ ($\pm 1.21\%$)
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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Doc Date: 07 Mar 22
End of certificate

Calibration Certificate



Pyranometer ISO 9847 Calibration

Certificate Number: GSACA-2048

Calibrated Instrument

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

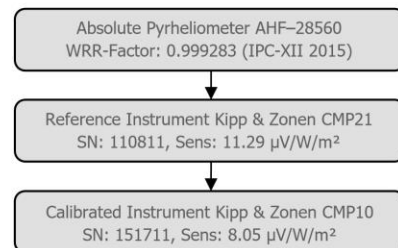
Calibration Date: 07 March 2022
Serial Number: 151711
New Sensitivity: 8.05 $\mu\text{V}/\text{W}/\text{m}^2$

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° , longitude 18.84085° and altitude 119 m AMSL and was concluded on 07 March 2022 at 15:39. 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: 565 [563 - 566] W/m^2
Ambient Temperature: 24.7 [24.5 - 24.8] $^\circ\text{C}$
Reference Instrument Temp.: 25.6 [25.5 - 25.6] $^\circ\text{C}$

Original Calibration

Original Sensitivity: 8.04 $\mu\text{V}/\text{W}/\text{m}^2$
Original Calib. Date: 28 August 2015

Calibration Results

New Sensitivity: 8.05200 $\mu\text{V}/\text{W}/\text{m}^2$
Sensitivity Standard Deviation (σ_{n-1}): 0.00359 $\mu\text{V}/\text{W}/\text{m}^2$
Calibration Uncertainty ($k = 2$): $\pm 0.097 \mu\text{V}/\text{W}/\text{m}^2 (\pm 1.21\%)$
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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Doc Date: 07 Mar 22
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 – A1091 |
| 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 ⁻² hourly averages ±8% ±10 W.m ⁻² individual readings |
| Range | 0 to >2000 W.m ⁻² |
| Analogue output sensitivity | 1mV = 1 W.m ⁻² |



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SPN1 Service and Recalibration Report

R8129

| | | |
|---------------------------|----------------------------|----------------|
| SPN1 Serial Number: A1091 | Serviced by: Jamie Patrick | Date: 25/03/22 |
|---------------------------|----------------------------|----------------|

Inspection

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

Dome Good.

Seal Good.

Shadow mask Good.

Bezel Bezel replaced.

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 : 2.4%