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## Station Information Report

# Solar and Meteorological Station

Pacific Power Association – Funafuti, Tuvalu

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Revision	Date	Author	Checked	Approved	Comments
Rev 0	06 Mar 2020	M. de Jager	M. King	M. de Jager	First Issue
Rev 1					
Rev 2					

## Contents

1	Introduction .....	2
2	Station Summary .....	3
3	Map of area.....	4
4	Site layout.....	5
5	Instrument list, serial numbers and multipliers.....	7
6	Supporting hardware and communication peripherals.....	8
7	Data logger wiring .....	8
8	Power circuit diagram.....	10
9	Detail Photographs .....	11
10	Terrain Photographs.....	18
11	Station Photographs.....	25
12	Calibration Certificates .....	32

## 1 Introduction

The World Bank initiated the Sustainable Energy Industry Development Project (SEIDP) to, amongst others, support the Pacific Power Association (PPA) in doing renewable energy resource assessments. The focus for this particular section of the project is to get high quality bankable wind as well as irradiance measurements supported by high quality meteorological measurements and to promote the awareness of the resource potential of wind and solar energy.

GeoSUN Africa is to execute the on-site measurement related aspects of the solar section of the project. The assignment for GeoSUN Africa is the following:

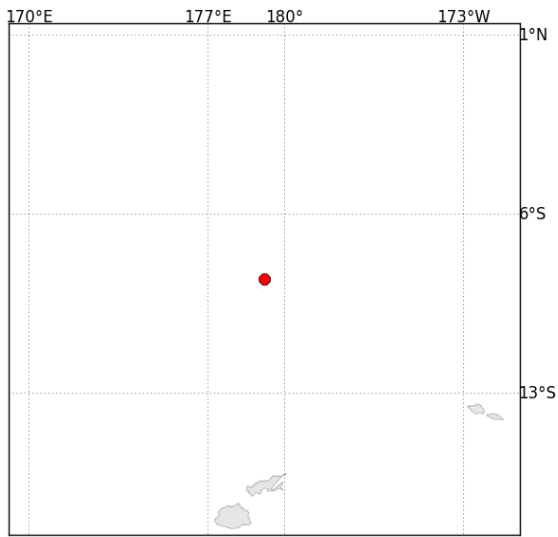
- An inception mission which involves visiting the proposed site locations and selecting the optimal location for the measurement equipment. The outcome of this inception mission is this implementation plan where sites and stations tiers are proposed;
- Providing high quality measuring equipment for each site, in line with the technical specifications;
- Installation of measurement equipment as well as subsequent Site Installation Report and photographs for each site;
- Hosting and providing two years of high quality, 'bankable' meteorological data relevant for solar resource assessment and project development;
- Ensuring maintenance, security, local cleaning/caretaking, and mitigation against extreme weather events and corrosion;
- Ensuring strong local involvement and capacity building at all stages of the measurement campaign;
- Decommissioning of all sites at the end of the measurement campaign, unless separate arrangements are made with one or more host institutions to continue with measurements outside of this assignment/contract.

This document acts as the Site Installation Report which follows the commissioning of the site, outlining the site location, site characteristics, technical specifications, calibration procedures, and all other relevant information to allow data users to fully understand the site and ensure the bankability of the measurement data. The Site Installation Report contains photographs of the site and the surrounding terrain.

The measurement data from the site will be continuously transferred to GeoSUN's central data repository, and shall then be transferred to the PPA on a monthly basis in both raw and quality-controlled formats according to the specifications developed by ESMAP. This data will be delivered via an online file sharing platform one month in arrears. Site Measurement Reports will accompany the delivery of monthly data, and shall detail any issues with the site or equipment, field calibration procedure, and any notable conclusions or results.

The assignment shall be deemed completed once two years of concurrent data is delivered in compliance with the minimum data recovery rates specified. At this point the vendor shall decommission each site and remove the solar measurement equipment, unless alternative arrangements outside the scope of this assignment/contract are made and endorsed by the relevant client/host agency.

## 2 Station Summary

<b>Work performed</b>	Installation and commissioning of solar and meteorological measurement station
<b>Commissioning date</b>	05 March 2020
<b>Planned decommissioning date</b>	05 March 2022
<b>Client</b>	Pacific Power Association
<b>Client contact person and contact details</b>	Name: Wairarapa J. Young Email: rapa@ppa.org.fj Telephone: (679) 330 6022
<b>Site location</b>	<p>Next to the runway between the entrances of the Meteorological Department and the National Power Utility (TEC)</p> 
<b>Access</b>	Starting at the airport terminal, cross the runway using the road on the side of the terminal building. The station is located at T-junction on the opposite side of the runway at the pedestrian gate of the Meteorological Department.
<b>Coordinates</b>	08° 31' 31.1" S, 179° 11' 46.8" E (-8.525087, 179.1963230)
<b>Elevation</b>	0 m AMSL
<b>Time zone (local and data logger)</b>	GMT +12 local time zone
<b>Name and contact details of on-site contact person(s)</b>	Name: Namoto Kelisiano Phone: 00 688 20295

### 3 Map of area



Figure 1: Map of the surrounding area (Source: Google Earth)

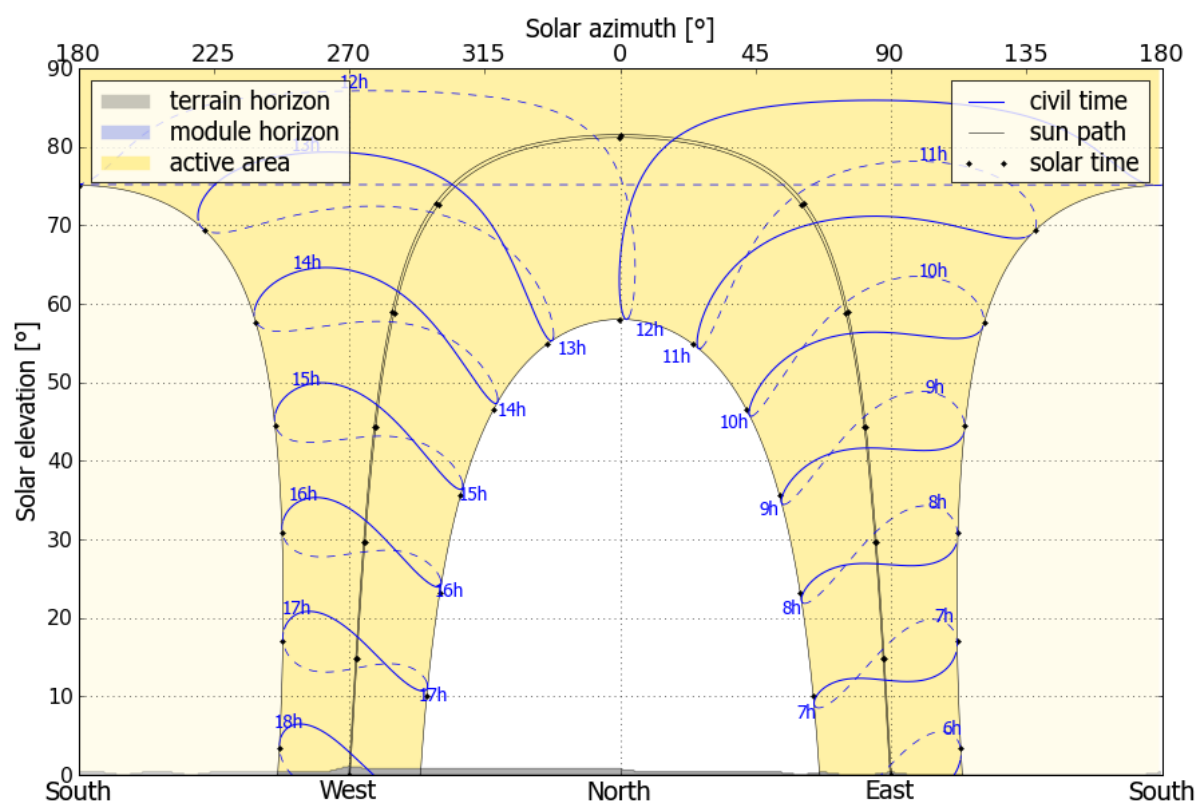


Figure 2: Terrain horizon and day length (Source: Solargis)

## 4 Site layout

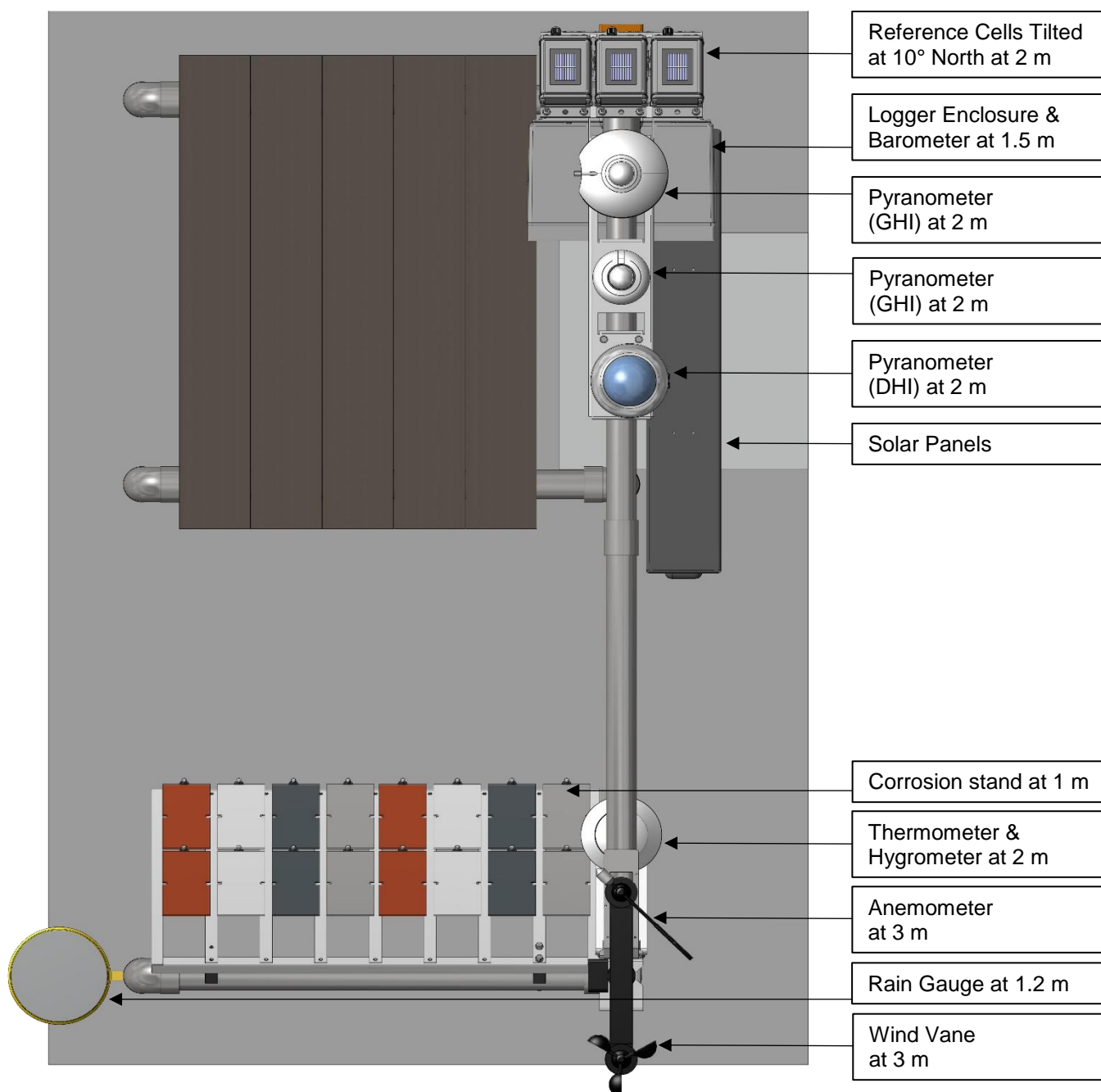


Figure 3: Site Layout (plan view)

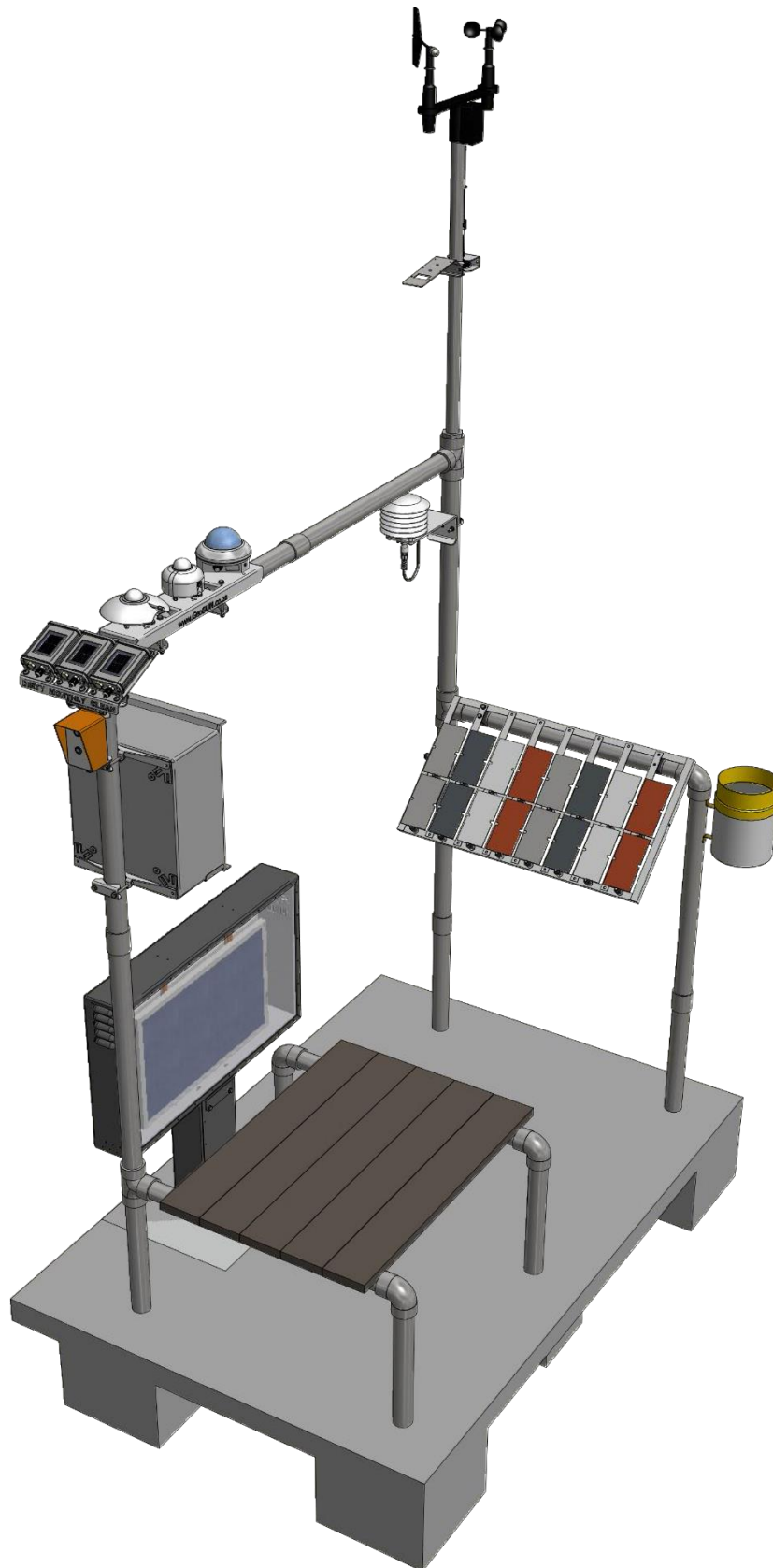


Figure 4: Site Layout (perspective view)

## 5 Instrument list, serial numbers and multipliers

Instrument (Measurement)	Make and Model	Serial Number	Variable Name (Program)	Multiplier
Pyranometer (GHI)	Hukseflux SR30-D1	4267	GHI_1	9.91 $\mu\text{V/W/m}^2$
Pyranometer (GHI)	Hukseflux SR20-T2	10501	GHI_2	15.94 $\mu\text{V/W/m}^2$
Pyranometer (DHI)	Delta Electronics SPN 1	A2064	DHI_SPN1	1
Reference Cell Clean	Ingenieurbüro Si-mV-85-A	85-00205-17-19350104	RefCellClean	57.51 $\mu\text{V/W/m}^2$
Reference Cell Monthly	Ingenieurbüro Si-mV-85-A	85-00205-17-19350114	RefCellMonthly	58.67 $\mu\text{V/W/m}^2$
Reference Cell Dirty	Ingenieurbüro Si-mV-85-A	85-00205-17-19350115	RefCellDirty	58.00 $\mu\text{V/W/m}^2$
3-Cup Anemometer (Wind Speed)	RM Young 03002	016669	WSpd	0.2 Offset 0.75 Slope
Wind Vane (Wind Direction)	RM Young 03002	016669	WDir	0 Offset 352 Slope
Temperature Sensor (Ambient Temperature)	Campbell Scientific CS215	E22440	Temp	1
Relative Humidity Sensor (Relative Humidity)	Campbell Scientific CS215	E22440	RH	1
Barometer (Atmospheric Pressure)	Vaisala PTB110	R3331021	BP	500 offset 0.24 slope
Rain Gauge (Rain)	Texas Electronics TR-525I	81185-819	Rain	0.2 mm/tip
Corrosion Plate	Make	Sample	Position (Column, Row)	Mass (g)
Mild Steel plate (Corrosion Testing)	Orytech Mild Steel	B3	C5, R1	132.3939
		B4	C5, R2	131.7867
		B5	C1, R1	135.1957
		B6	C1, R2	132.4306
H.D. Galvanised (Zinc) plate (Corrosion Testing)	Orytech H.D. Galvanised (Zinc)	B3	C7, R1	80.9162
		B4	C7, R2	82.7634
		B5	C3, R1	80.9041
		B6	C3, R2	81.7435
Copper plate (Corrosion Testing)	Orytech Copper	B3	C8, R1	83.2748
		B4	C8, R2	82.1146
		B5	C4, R1	81.2054
		B6	C4, R2	80.5177
Aluminium plate (Corrosion Testing)	Orytech Aluminium	B3	C6, R1	37.5579
		B4	C6, R2	37.5453
		B5	C2, R1	37.7676
		B6	C2, R2	37.8469

## 6 Supporting hardware and communication peripherals

Data Logger	Campbell Scientific CR1000X (OS:Std.03.02)
Communication	RS232 (115200) TCP/IP
Pakbus Address	786
Password Set	None
Modem	Campbell Scientific CELL215 Cellular Module
Network Details	Service provider: Telecom Phone number: +688 711 4134
Modem Power Control	CS I/O Port
Data Logger Clock	GMT+12
Main Battery	2 x 12 V / 24 Ah
Solar Panel(s)	2 x 25 W
Charge Controller	2 x CPL Research (10 A)

## 7 Data logger wiring

PPA Wiring Diagram November 2019- CR1000x							
Logger Port	Accessories	Connection	Instrument Cable	Function	Reading	Instrument	
	250mA Fast-Blow	C7	Grey	A-	GHI1	SR30	
		C8	White	B+			
		AGB	Shield	GND			
		PB-Fused	Brown	12V			
		GB	Black	0V			
			Blue	NC			
			3H	White	Signal +	GHI2	SR20
			3L	Green	Signal -		
			AGB	Black	GND		
		SW12-2		Yellow	Heater +		
		G	Brown	Heater -			
VX1	10kΩ 0.1% Resistor	SE4	Red+Pink	Temp +			
		AG2	Blue+Grey	Temp -	DHI	SPN1	
		5H	White	GHI +			
		6H	Brown	DHI +			
		5L	Green	Signal -			
		6L	Bridged with 5L/Signal -				
		GB	Grey	0 V			
		PB	Pink	12 V			

SW12-2		Red	Heater +		
	G	Blue	Heater -		
	AGB	Clear	GND		
	NC	Yellow	Sun		
	PB	Red	12 V		
	C1	Green	Signal +	Temp & RH	CS215
	GB	White	0 V		
	GB	Black	0 V		
	AGB	Clear	GND		
	SE13	Orange	Signal +	Clean	Ref cell
	AG6	Blue	Signal -		
	AGB	Black	GND		
	SE14	Orange	Signal +	Monthly	Ref cell
	AG7	Blue	Signal -		
	AGB	Black	GND		
	SE15	Orange	Signal +	Dirty	Ref cell
	AG7	Blue	Signal -		
	AGB	Black	GND		
	VX2	Blue	Excitation	Wind Speed & Direction	03002
	SE16	Green	Signal +		
	AG8	White	Signal -		
	AGB	Clear	GND		
	P1	Red	Signal +		
	AGB	Clear	GND		
	P2	Black	Signal +	Rain	TE525
	AG	White	Signal -		
	AGB	Clear	GND		
	C5	Red	Signal +	Clean	Clean Button
	C2	Green	Light +		
	C3	Blue	Signal -		
	AGB	Clear	GND		
	C4	Yellow	Signal +	Monthly	Monthly Button
	C2	Green	Light +		
	C3	Blue	Signal -		
	AGB	Clear	GND		
	C6	Red	Signal +	Gate	Switch
	G	Blue	Signal -		
	AGB	Clear	GND		
	SE7	Blue/Brown	Signal +	Pressure	PTB110
	12V	Red	12V		
	5V	Green	Signal +		
	G	Black	Signal -		
	AG	Yellow/White	GND		
	AG	Clear	GND		

## 8 Power circuit diagram

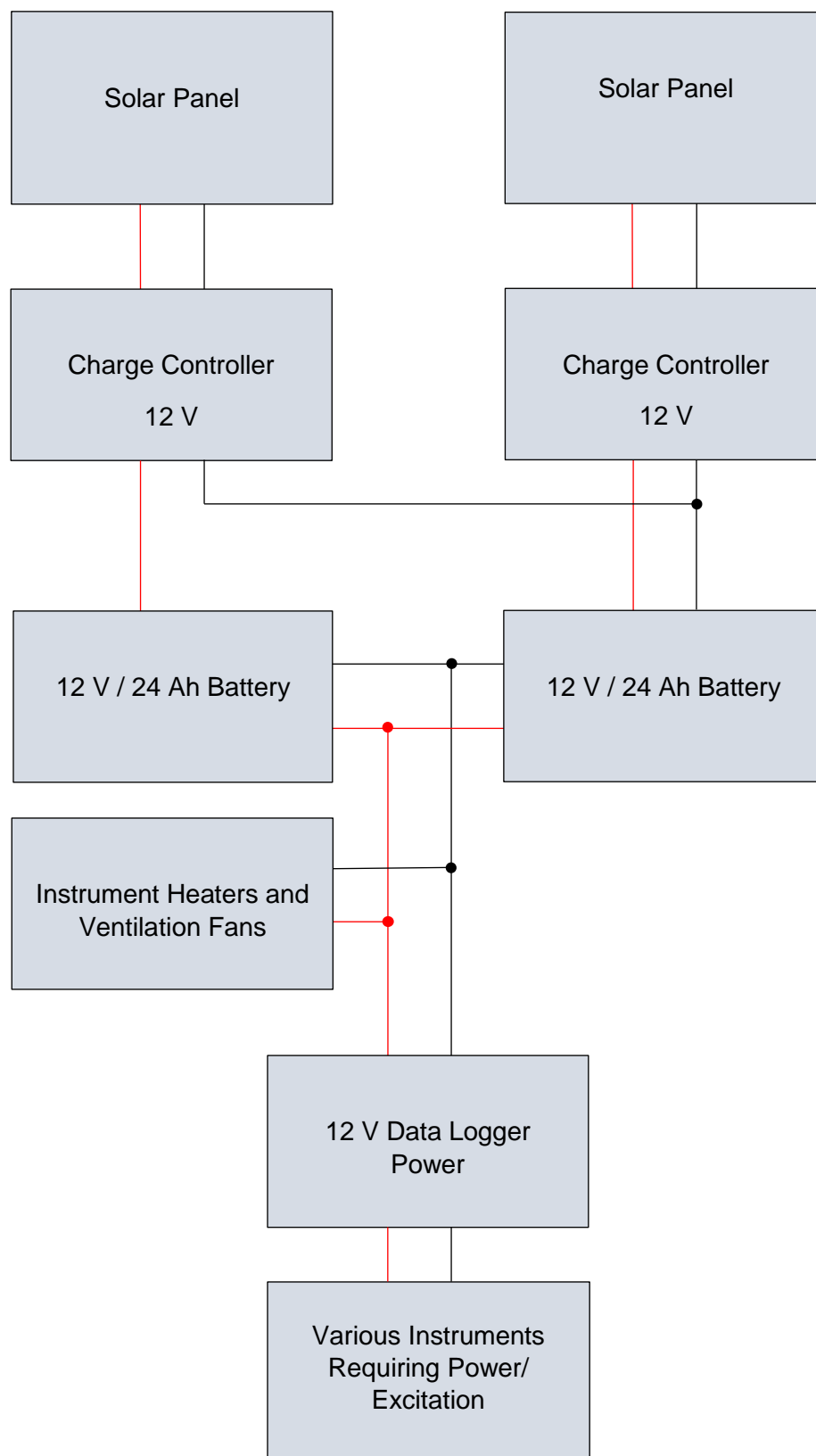


Figure 5: The DC power circuit

## 9 Detail Photographs

This section showcases details of the installation, including the main station components. Records are shown of instrument makes, models and serial numbers, as well as the installation levels and orientation where applicable.

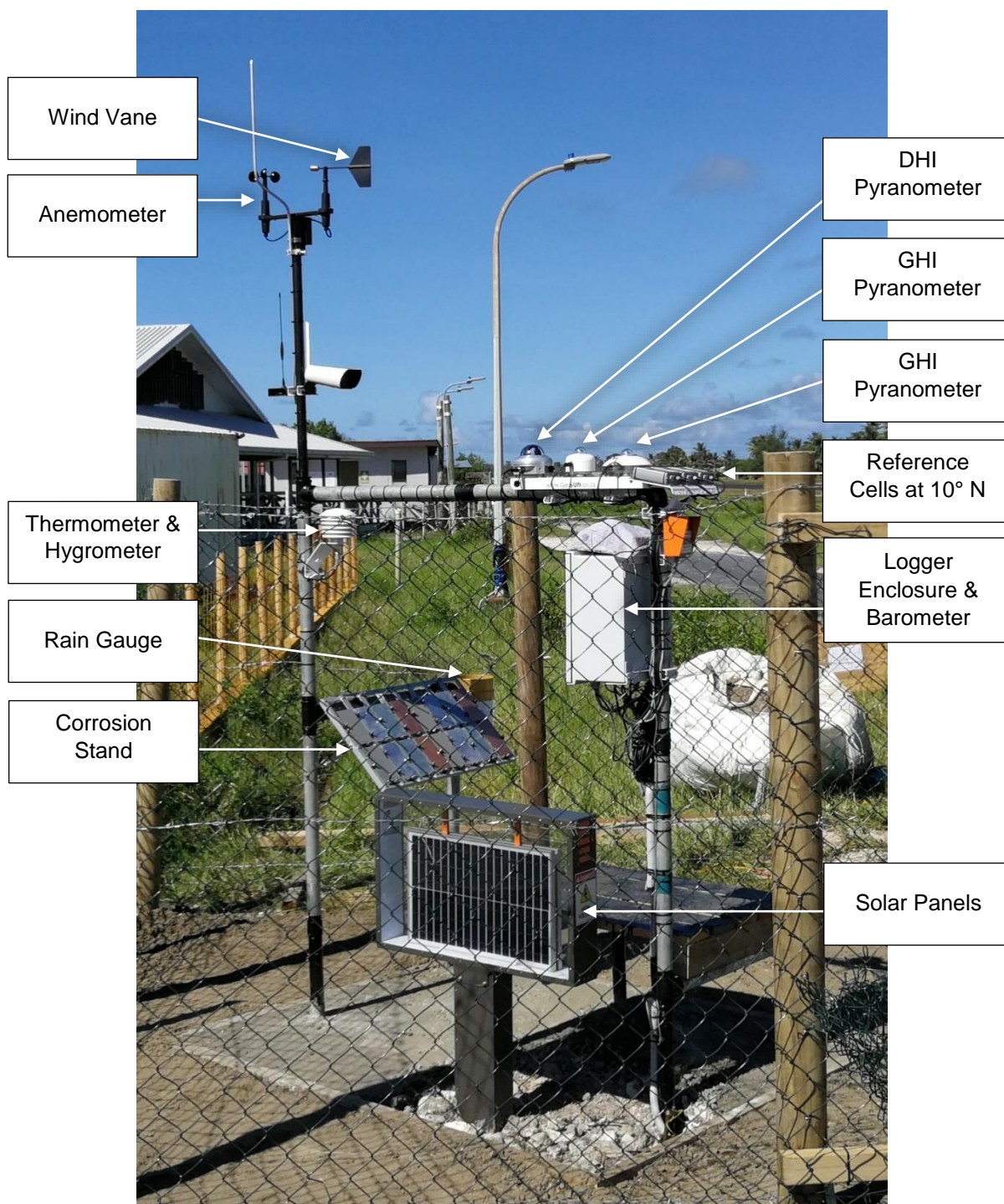


Figure 6: Station Summary



Figure 7: GHI (1) Pyranometer Installation



Figure 8: GHI (2) Pyranometer Installation



Figure 9: DHI Pyranometer Installation



Figure 10: Wind instruments at 3 m



Figure 11: Thermometer and Hygrometer at 2 m



Figure 12: Corrosion Test Stand



Figure 13: Rain Gauge

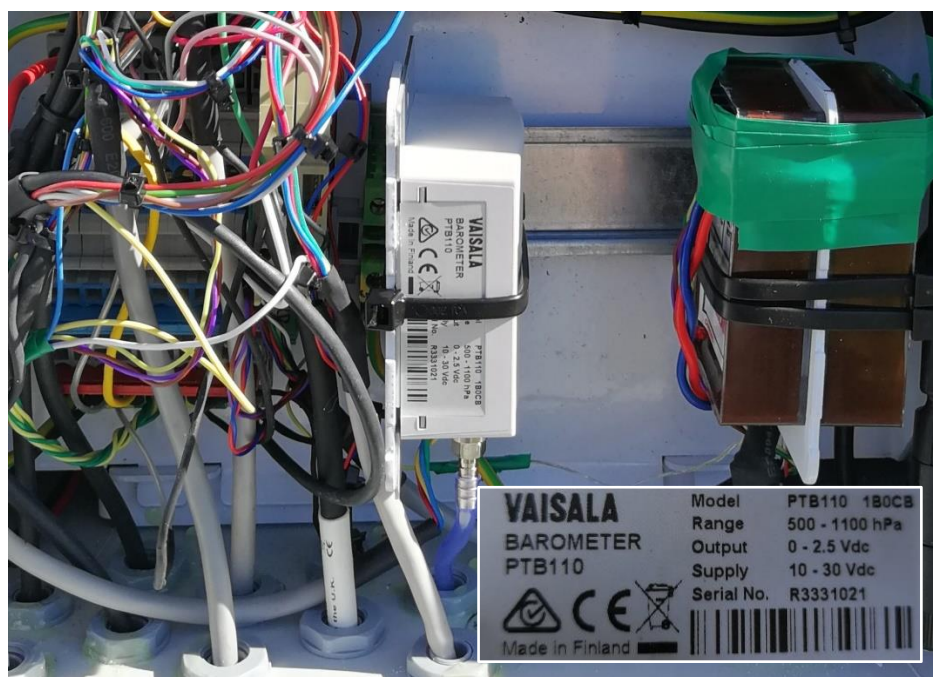


Figure 14: Barometer



Figure 15: Reference Cells at 10° North



Figure 16: Solar Panel



Figure 17: Logger Enclosure

## 10 Terrain Photographs

Obstacles protruding higher than the horizon as viewed from the solar instruments will affect lower solar elevation readings if they fall within the sun path as depicted in Figure 2. The pictures in this section shows the terrain surrounding the station at the time of installation, giving an indication of near or far shading influences on the station.



Figure 18: 0/360 Degrees (North)



Figure 19: 30 Degrees



Figure 20: 60 Degrees



Figure 21: 90 Degrees (East)



Figure 22: 120 Degrees



Figure 23: 150 Degrees



Figure 24: 180 Degrees (South)



Figure 25: 210 Degrees



Figure 26: 240 Degrees



Figure 27: 270 Degrees (West)



Figure 28: 300 Degrees



Figure 29: 330 Degrees

## 11 Station Photographs

This section indicates the station within the surrounding terrain to give an overall view thereof, as well as provide additional context to the possible near and far shading influences.



Figure 30: 0/360 Degrees (From North)



Figure 31: 30 Degrees



Figure 32: 60 Degrees



Figure 33: 90 Degrees (From East)



Figure 34: 120 Degrees



Figure 35: 150 Degrees



Figure 36: 180 Degrees (From South)



Figure 37: 210 Degrees



Figure 38: 240 Degrees



Figure 39: 270 Degrees (From West)



Figure 40: 300 Degrees



Figure 41: 330 Degrees

## 12 Calibration Certificates



**Hukseflux Thermal Sensors B.V.**  
www.hukseflux.com  
info@hukseflux.com

### Calibration certificate

Pages 1  
Release date: 24 SEP, 2019

Product code **SR30-D1**  
Product identification **serial number 4267**  
Product type pyranometer  
Measurand hemispherical solar radiation

#### Calibration result

Sensitivity  **$S = 9.91 \times 10^{-6} \text{ V/(W/m}^2\text{)}$**   
Calibration uncertainty  **$\pm 0.10 \times 10^{-6} \text{ V/(W/m}^2\text{)}$**

the number following the  $\pm$  symbol is the expanded uncertainty with a coverage factor  $k = 2$ , and defines an interval estimated to have a level of confidence of 95 percent

Reference conditions 20 °C, normal incidence solar radiation, horizontal mounting, irradiance level 1000 W/m<sup>2</sup>

#### Measurement process

Metrological characteristic S in [V/(W/m<sup>2</sup>)]: sensitivity to irradiance in the 300 to 3000 x 10<sup>-9</sup> W/m<sup>2</sup> range, with 180° field of view angle, valid for reference conditions  
Calibration method indoor calibration according to ISO 9847, type IIC  
Measurement equipment Hukseflux Solar Radiation Calibration

#### Metrological traceability

Calibration traceability to WRR (World Radiometric Reference)  
Calibration hierarchy from WRR through ISO 9846 and ISO 9847  
Working standard pyranometer type SR30-D1, serial number 2484  
Calibration institute PMOD World Radiation Center, Davos, Switzerland  
Standard sensitivity  $9.94 \times 10^{-6} \text{ V/(W/m}^2\text{)}$

#### Evaluation of the uncertainty of the calibration result

Uncertainty calculation the calibration uncertainty calculated as the square root of the sum of the squares of the calibration uncertainty of the working standard, the uncertainty of the method and the uncertainty due to deviations from the reference conditions is  $\pm 1.0 \%$ .

#### Person performing calibration:

N.E. Handayani

#### Calibration Date:

20 SEP, 2019

#### Person authorising calibration result of product:

M. Rietveld

#### Date:

24 SEP, 2019

Certificate identification: 201909.SR30-D1.4267.01

page 1/1



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www.hukseflux.com  
info@hukseflux.com

## Product certificate

Pages: 4  
Release date: 24 SEP, 2019

Product code **SR30-D1**  
Product identification **serial number 4267**  
Product type pyranometer  
Measurand hemispherical solar radiation  
Classification secondary standard (ISO 9060), high quality (WMO-No. 8)

### Calibration result

Sensitivity  **$S = 9.91 \times 10^{-6} \text{ V/(W/m}^2\text{)}$**   
Calibration uncertainty  **$\pm 0.10 \times 10^{-6} \text{ V/(W/m}^2\text{)}$**

the number following the  $\pm$  symbol is the expanded uncertainty with a coverage factor  $k = 2$ , and defines an interval estimated to have a level of confidence of 95 percent

### Product specifications and conformity

1:	ISO 9060 secondary standard	<b>verified</b>
2:	resistance	<b>18.9 <math>\Omega</math></b>
3:	insulation resistance	<b>&gt; 100 x 10<sup>6</sup> <math>\Omega</math></b>
4:	response time (95 %)	<b>3.1 s</b>
5:	temperature response	<b>verified</b>
6:	directional response	<b>verified</b>
7:	tilt measurement uncertainty	<b><math>\pm 1^\circ</math> (0 to 90 °)</b>

**Table 0.1** connections

PIN	WIRE	
1	Brown	VDC [+]
4	Black	VDC [-]
3	Blue	not connected
2	White	RS-485 B / B' [+]
5	Grey	RS-485 A / A' [-]
	Yellow	shield

Calibration procedure according to ISO 9847. Traceability of calibration is to the WRR (World Radiometric Reference) maintained at the World Radiation Center in Davos, Switzerland.

Please consult the user manual for set up, operation and maintenance instructions, and information on measurement uncertainty during actual use.

**Person authorising acceptance and release of product:**  
M. Rietveld

**Date:**  
24 SEP, 2019



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## Directional response

Pages: 4  
Release date: 24 SEP, 2019

Product code **SR30-D1**  
Product identification **serial number 4267**  
Product type pyranometer  
Measurand hemispherical solar radiation  
Classification secondary standard (ISO 9060), high quality (WMO-No. 8)

### Characterisation result

Directional response  $\leq \pm 3.2 \text{ W/m}^2$

### Measurement process

Characterised parameter dependence of sensitivity resulting from the direction of irradiance (a measure of the deviations from an ideal cosine response and its azimuthal variation)

Measurement functions  $C_{rel} = S(\theta)/(S(0) \cdot \cos(\theta) - 1) \cdot 100 \%$   
with  $C_{rel}$  the deviation from an ideal cosine response at zenith angle  $\theta$  in [%],  $S(\theta)$  the sensitivity to beam irradiance at zenith angle  $\theta$  in  $[V/(W/m^2)]$ ,  $S(0)$  the sensitivity to beam irradiance at normal incidence,  $\theta$  the incoming angle from zenith in  $[\circ]$   
 $C_{abs} = (S(\theta)/(S(0) \cdot \cos(\theta) - 1)) \cdot \cos(\theta) \cdot 1000$   
with  $C_{abs}$  the directional response as defined below in  $[W/m^2]$

Measurement equipment Hukseflux Directional Response Characterisation

### Conformity assessment

Definition of measurand The directional response is the error caused by assuming that the reported sensitivity is valid when measuring from any direction a beam whose normal incidence is  $1000 \text{ W/m}^2$

Acceptance interval ISO 9060 specifies a limit on the directional response for a secondary standard pyranometer of  $\pm 10 \text{ W/m}^2$

Conclusion Conformity verified

**Table 0.2** directional response test result

DIRECTIONAL RESPONSE TEST								
azimuth	North		East		South		West	
zenith	$C_{abs}$ [W/m <sup>2</sup> ]	$C_{rel}$ [%]	$C_{abs}$ [W/m <sup>2</sup> ]	$C_{rel}$ [%]	$C_{abs}$ [W/m <sup>2</sup> ]	$C_{rel}$ [%]	$C_{abs}$ [W/m <sup>2</sup> ]	$C_{rel}$ [%]
40 °	+0.1	+0.0	-0.4	-0.1	-1.3	-0.2	-1.4	-0.2
60 °	+0.4	+0.1	-0.1	+0.0	-1.1	-0.2	-1.5	-0.3
70 °	+0.4	+0.1	+0.0	+0.0	-0.8	-0.2	-1.7	-0.5
80 °	+2.7	+1.6	+3.2	+1.8	+2.4	+1.4	+1.5	+0.9

Person performing characterisation:  
K. Ismail

Date:  
18 SEP, 2019



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## Temperature response

Pages: 4  
Release date: 24 SEP, 2019

Product code **SR30-D1**  
Product identification **serial number 4267**  
Product type pyranometer  
Measurand hemispherical solar radiation  
Classification secondary standard (ISO 9060), high quality (WMO-No. 8)

### Characterisation result

Temperature response **< ± 0.03 % (-30 to +50 °C)**  
Temperature coefficients\*  
**a = -19.7616 × 10<sup>-6</sup> °C<sup>-2</sup>**  
**b = 2.8448 × 10<sup>-4</sup> °C<sup>-1</sup>**  
**c = 1.0022**

\* These temperature coefficients are applied internally in the instrument

### Measurement process

Characterised parameter dependence of sensitivity to ambient temperature  
Measurement function  $S(T) = S_0 \cdot (a \cdot T^2 + b \cdot T + c)$   
with  $S(T)$  sensitivity in [V/(W/m<sup>2</sup>)] at an instrument body temperature  
 $T$ ,  $S_0$  sensitivity at 20 °C instrument body temperature,  $T$  the  
instrument body temperature in [°C],  $a$ ,  $b$  and  $c$  the temperature  
coefficients determined from a second order polynomial fit  
Hukseflux Temperature Response Characterisation

Measurement equipment

### Conformity assessment

Definition of measurand\* Temperature response is the remaining percentage deviation in  
sensitivity due to change in ambient temperature within a temperature  
interval after the temperature coefficients are applied  
Temperature interval -30 to +50 °C  
Acceptance interval Hukseflux specifies a limit on the temperature response for a  
SR30-D1 of ± 0.4 %  
Conclusion Conformity verified

\* This is an adaptation of the definition in ISO 9060, which specifies a limit on the temperature response for a  
secondary standard pyranometer of 2 % within a temperature interval of 50 K.

**Table 0.3** temperature dependence test result

#### TEMPERATURE DEPENDENCE TEST

T [°C]	-30	-10	10	30	50
remaining deviation	+0.02 %	-0.03 %	+0.00 %	+0.03 %	-0.02 %

**Person performing characterisation:**  
H.A. Kaniş

**Date:**  
18 SEP, 2019



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info@hukseflux.com

## Tilt sensor characterisation

Pages: 4  
Release date: 24 SEP, 2019

Product code	<b>SR30-D1</b>
Product identification	<b>serial number 4267</b>
Product type	pyranometer
Measurand	hemispherical solar radiation
Classification	secondary standard (ISO 9060), high quality (WMO-No. 8)

Characterisation result*	x-axis	y-axis	z-axis
gain	1.0045	1.0033	1.0163
offset	-289	204	22
temperature coefficient $a_0$	$-0.0135 \times 10^{-12}$	$0.9850 \times 10^{-12}$	$0.0093 \times 10^{-12}$
temperature coefficient $a_1$	0.2252	0.4097	-0.8673
temperature coefficient $a_2$	$0.1759 \times 10^{-2}$	$-0.1000 \times 10^{-2}$	$-0.6591 \times 10^{-2}$
temperature coefficient $a_3$	$0.1197 \times 10^{-4}$	$0.7569 \times 10^{-4}$	$-0.8412 \times 10^{-4}$

\* These gains, offsets and temperature coefficients are applied internally in the instrument

### Measurement process

Characterised parameters	tilt sensor gains and offsets
Measurement equation	$\theta = 360/2\pi \cdot \arctan((x^2 + y^2)^{1/2}/z)$ $x, y, z = \text{gain}_{x,y,z} \cdot \text{raw}_{x,y,z} + \text{offset}_{x,y,z} + d_{x,y,z}(T)$ $d_{x,y,z}(T) = a_{0x,0y,0z} + a_{1x,1y,1z} \cdot T + a_{2x,2y,2z} \cdot T^2 + a_{3x,3y,3z} \cdot T^3$ <p>with <math>\theta</math> the sensor tilt angle with respect to the horizontal in [°],  <math>\arctan</math> the arctangent function, <math>x</math>, <math>y</math> and <math>z</math> the corrected accelerometer counts, <math>\text{gain}_{x,y,z}</math> the tilt sensor gains, <math>\text{raw}_{x,y,z}</math> the raw accelerometer counts, <math>\text{offset}_{x,y,z}</math> the tilt sensor offsets, <math>d_{x,y,z}(T)</math> the correction for temperature dependence of the tilt measurement at an instrument body temperature <math>T</math>, <math>a_0</math>, <math>a_1</math>, <math>a_2</math> and <math>a_3</math> the temperature coefficients determined from a third order polynomial fit. Labels <math>x</math>, <math>y</math> and <math>z</math> refer to the three accelerometer axes.</p>
Measurement process	<p>Alignment with the bubble level is attained in horizontal position by introducing gains and offsets.</p> <p>Gains and offsets are determined in horizontal position and at a tilt angle of 90 °. Temperature dependence of the tilt measurement is determined at a tilt angle of 90 ° between -30 and + 50 °C.</p>
Measurement method	Hukseflux Tilt Sensor Characterisation
<b>Conformity assessment</b>	
Description of assessment	The tilt measurement uncertainty is verified in horizontal position and at a tilt angle of 90 °
Acceptance interval	The tilt measurement uncertainty is specified at $\pm 1^\circ$ (0 to 90 °)
Conclusion	Conformity verified

**Person performing tilt sensor characterisation:**  
L. Asaa

**Date:**  
24 SEP, 2019



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info@hukseflux.com

## Calibration certificate

Pages 1  
Release date: 24 SEP, 2019

Product code **SR20-T2**  
Product identification **serial number 10501**  
Product type pyranometer  
Measurand hemispherical solar radiation

### Calibration result

Sensitivity  **$S = 15.94 \times 10^{-6} \text{ V/(W/m}^2\text{)}$**   
Calibration uncertainty  **$\pm 0.16 \times 10^{-6} \text{ V/(W/m}^2\text{)}$**

the number following the  $\pm$  symbol is the expanded uncertainty with a coverage factor  $k = 2$ , and defines an interval estimated to have a level of confidence of 95 percent

Reference conditions 20 °C, normal incidence solar radiation, horizontal mounting, irradiance level 1000 W/m<sup>2</sup>

### Measurement process

Metrological characteristic  $S$  in [V/(W/m<sup>2</sup>)]: sensitivity to irradiance in the 300 to 3000 x 10<sup>-9</sup> m range, with 180° field of view angle, valid for reference conditions

Calibration method indoor calibration according to ISO 9847, type IIc  
Measurement equipment Hukseflux Solar Radiation Calibration

### Metrological traceability

Calibration traceability to WRR (World Radiometric Reference)  
Calibration hierarchy from WRR through ISO 9846 and ISO 9847  
Working standard pyranometer type SR20, serial number 5039  
Calibration institute PMOD World Radiation Center, Davos, Switzerland  
Standard sensitivity  $14.60 \times 10^{-6} \text{ V/(W/m}^2\text{)}$

### Evaluation of the uncertainty of the calibration result

Uncertainty calculation the calibration uncertainty calculated as the square root of the sum of the squares of the calibration uncertainty of the working standard, the uncertainty of the method and the uncertainty due to deviations from the reference conditions is  $\pm 1.0 \%$ .

### Person performing calibration:

D. Bemelman

### Calibration Date:

24 SEP, 2019

### Person authorising calibration result of product:

H.E. Brouwer

### Date:

24 SEP, 2019



**Hukseflux Thermal Sensors B.V.**  
www.hukseflux.com  
info@hukseflux.com

## Product certificate

Pages: 3  
Release date: 24 SEP, 2019

Product code **SR20-T2**  
Product identification **serial number 10501**  
Product type pyranometer  
Measurand hemispherical solar radiation  
Classification secondary standard (ISO 9060), high quality (WMO-No. 8)

### Calibration result

Sensitivity  **$S = 15.94 \times 10^{-6} \text{ V/(W/m}^2\text{)}$**   
Calibration uncertainty  **$\pm 0.16 \times 10^{-6} \text{ V/(W/m}^2\text{)}$**

the number following the  $\pm$  symbol is the expanded uncertainty with a coverage factor  $k = 2$ , and defines an interval estimated to have a level of confidence of 95 percent

Measurement function  **$E = U/S$**   
with  $E$  irradiance in  $[\text{W/m}^2]$ ,  $U$  voltage output in  $[\text{V}]$

### Product specifications and conformity

1:	ISO 9060 secondary standard	<b>verified</b>
2:	resistance	<b>65.8 <math>\Omega</math></b>
3:	insulation resistance	<b><math>&gt; 100 \times 10^6 \Omega</math></b>
4:	response time (95 %)	<b>4.0 s</b>
5:	temperature response*	<b>verified</b>
6:	directional response	<b>verified</b>

\*see separate certificate; result may be used to improve measurement quality

**Table 0.1 connections**

PIN	WIRE	
2	Red	10 k $\Omega$ thermistor [+]
3	Pink	10 k $\Omega$ thermistor [+]
6	Blue	10 k $\Omega$ thermistor [–]
8	Grey	10 k $\Omega$ thermistor [–]
1	Brown	heater
4	Yellow	heater
9	Black	ground
7	White	signal [+]
5	Green	signal [–]

The 10 k $\Omega$  thermistor is a single four-wire thermistor measuring instrument body temperature.

Calibration procedure according to ISO 9847. Traceability of calibration is to the WRR (World Radiometric Reference) maintained at the World Radiation Center in Davos, Switzerland.

Please consult the user manual for set up, operation and maintenance instructions, and information on measurement uncertainty during actual use.

**Person authorising acceptance and release of product:**  
H.E. Brouwer

**Date:**  
24 SEP, 2019



**Hukseflux Thermal Sensors B.V.**  
www.hukseflux.com  
info@hukseflux.com

## Directional response

Pages: 3  
Release date: 24 SEP, 2019

Product code **SR20-T2**  
Product identification **serial number 10501**  
Product type pyranometer  
Measurand hemispherical solar radiation  
Classification secondary standard (ISO 9060), high quality (WMO-No. 8)

### Characterisation result

Directional response  $\leq \pm 8.1 \text{ W/m}^2$

### Measurement process

Characterised parameter dependence of sensitivity resulting from the direction of irradiance (a measure of the deviations from an ideal cosine response and its azimuthal variation)

Measurement functions  $C_{\text{rel}} = S(\theta)/(S(0) \cdot \cos(\theta) - 1) \cdot 100 \%$   
with  $C_{\text{rel}}$  the deviation from an ideal cosine response at zenith angle  $\theta$  in [%],  $S(\theta)$  the sensitivity to beam irradiance at zenith angle  $\theta$  in  $[\text{V}/(\text{W/m}^2)]$ ,  $S(0)$  the sensitivity to beam irradiance at normal incidence,  $\theta$  the incoming angle from zenith in  $[\circ]$   
 $C_{\text{abs}} = (S(\theta)/(S(0) \cdot \cos(\theta) - 1)) \cdot \cos(\theta) \cdot 1000$   
with  $C_{\text{abs}}$  the directional response as defined below in  $[\text{W/m}^2]$   
Hukseflux Directional Response Characterisation

Measurement equipment

### Conformity assessment

Definition of measurand The directional response is the error caused by assuming that the reported sensitivity is valid when measuring from any direction a beam whose normal incidence is  $1000 \text{ W/m}^2$

Acceptance interval ISO 9060 specifies a limit on the directional response for a secondary standard pyranometer of  $\pm 10 \text{ W/m}^2$

Conclusion Conformity verified

**Table 0.2** directional response test result

DIRECTIONAL RESPONSE TEST								
azimuth	North		East		South		West	
zenith	$C_{\text{abs}}$ [W/m <sup>2</sup> ]	$C_{\text{rel}}$ [%]	$C_{\text{abs}}$ [W/m <sup>2</sup> ]	$C_{\text{rel}}$ [%]	$C_{\text{abs}}$ [W/m <sup>2</sup> ]	$C_{\text{rel}}$ [%]	$C_{\text{abs}}$ [W/m <sup>2</sup> ]	$C_{\text{rel}}$ [%]
40 °	+0.3	+0.0	-2.6	-0.3	+0.6	+0.1	+3.4	+0.4
60 °	-3.0	-0.6	-6.2	-1.2	-1.3	-0.3	+0.8	+0.2
70 °	-6.0	-1.8	-8.1	-2.4	-4.4	-1.3	-1.4	-0.4
80 °	-5.4	-3.1	-7.0	-4.0	-3.5	-2.0	-0.9	-0.5

**Person performing characterisation:**  
K. Ismail

**Date:**  
20 SEP, 2019



**Hukseflux Thermal Sensors B.V.**  
 www.hukseflux.com  
 info@hukseflux.com

## Temperature response

Pages: 3  
 Release date: 24 SEP, 2019

Product code **SR20-T2**  
 Product identification **serial number 10501**  
 Product type pyranometer  
 Measurand hemispherical solar radiation  
 Classification secondary standard (ISO 9060), high quality (WMO-No. 8)

### Characterisation result

Temperature response  $\pm 0.2 \%$   
 Temperature coefficients  
 $a = -7.0268 \times 10^{-6} \text{ } ^\circ\text{C}^{-2}$   
 $b = 2.3354 \times 10^{-4} \text{ } ^\circ\text{C}^{-1}$   
 $c = 0.9981$

### Measurement process

Characterised parameter dependence of sensitivity to ambient temperature  
 Measurement function  $S(T) = S_0 \cdot (a \cdot T^2 + b \cdot T + c)$   
 with  $S(T)$  sensitivity in  $[\text{V}/(\text{W}/\text{m}^2)]$  at an instrument body temperature  $T$ ,  $S_0$  sensitivity at  $20 \text{ } ^\circ\text{C}$  instrument body temperature,  $T$  the instrument body temperature in  $[\text{ } ^\circ\text{C}]$ ,  $a$ ,  $b$  and  $c$  the temperature coefficients determined from a second order polynomial fit  
 Measurement equipment Hukseflux Temperature Response Characterisation

### Conformity assessment

Definition of measurand Temperature response is the percentage deviation in sensitivity due to change in ambient temperature within an interval of  $50 \text{ K}$   
 Temperature interval  $-10 \text{ to } +40 \text{ } ^\circ\text{C}$   
 Acceptance interval ISO 9060 specifies a limit on the temperature response for a secondary standard pyranometer of  $2 \%$   
 Conclusion Conformity verified

**Table 0.3** temperature dependence test result

TEMPERATURE DEPENDENCE TEST									
T [°C]	-30	-20	-10	0	10	20	30	40	50
$\frac{S(T) - S_0}{S_0}$	-1.5 %	-0.9 %	-0.5 %	-0.2 %	+0.0 %	+0.0 %	-0.1 %	-0.4 %	-0.8 %

**Person performing characterisation:**  
 H.A. Kanij

**Date:**  
 19 SEP, 2019




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 – A2064
Date	24/09/19
Authorised Signature	

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:	$\pm 5\%$ daily integrals $\pm 5\% \pm 10 \text{ W.m}^{-2}$ hourly averages $\pm 8\% \pm 10 \text{ W.m}^{-2}$ individual readings
Range	0 to $>2000 \text{ W.m}^{-2}$
Analogue output sensitivity	$1\text{mV} = 1 \text{ W.m}^{-2}$

**Delta-T Devices Ltd**

130 Low Road, Burwell, Cambridge, CB25 0EJ, UK

Tel: +44 1638 742922 Fax: +44 1638 743155

email: [sales@delta-t.co.uk](mailto:sales@delta-t.co.uk) web: [www.delta-t.co.uk](http://www.delta-t.co.uk)

Calibration Certificate Silicon Irradiance Sensor

Sensor Type: Si-mV-85-A  
Serial No.: 85-00205-17-19350104  
Comment:

Irradiance Calibration with Artificial Light in Comparison to a Reference Cell

Calibrated by: Huhnstock-Breuer  
Date / Time: 28.08.2019 13:55

	Type	Calibration $\mu\text{V}/\text{W}/\text{m}^2$	Temperature Coefficient $1/^\circ\text{C}$	Output mV	Temperature $^\circ\text{C}$	Irradiance <sup>1)</sup> $\text{W}/\text{m}^2$
Reference Cell	Si-Ref mono PTB-1	56,51	0,00067	56,953	30,76	1004,0
	Type	Irradiance $\text{W}/\text{m}^2$	Correction Factor <sup>3)</sup>	Output mV	Temperature $^\circ\text{C}$	Calibration $\mu\text{V}/\text{W}/\text{m}^2$
Test Object	Si-mV-85-A	1004,0	0,994570	58,051	32,8	57,51

Test Equipment Irradiance Calibration

Manufacturer	Type	Serial No.	Calibration Certificate	Trace
Ingenieurbüro Mencke & Tegtmeier GmbH	Si-Ref mono PTB-1	02-20002-05-15309999	47109-PTB-18	PTB
Gantner Instruments	IDL100	191667	098220-02 D-K-15019-01-00	DKD
	ISM111	078743	098221-02 D-K-15019-01-00	DKD
OMEGA Engineering	IN510	9894	./.	./.

$$^1)\text{Irradiance} = \frac{\text{Output} \cdot 1000}{\text{Calibration} \cdot (1 + \text{Temperature Coefficient} \cdot (\text{Temperature} - 25))}$$

$$^2)\text{Calibration} = \frac{\text{Output} \cdot 1000 \cdot \text{Correction Factor}}{\text{Irradiance}}$$

<sup>3)</sup> Individual calculated for each Calibration Process, must not be used for Outdoor Application.

Calibration Certificate Silicon Irradiance Sensor

Sensor Type: Si-mV-85-A  
Serial No.: 85-00205-17-19350114  
Comment:

Irradiance Calibration with Artificial Light in Comparison to a Reference Cell

Calibrated by: Huhnstock-Breuer  
Date / Time: 28.08.2019 14:00

	Type	Calibration $\mu\text{V/W/m}^2$	Temperature Coefficient $1/^\circ\text{C}$	Output mV	Temperature $^\circ\text{C}$	Irradiance <sup>1)</sup> $\text{W/m}^2$
Reference Cell	Si-Ref mono PTB-1	56,51	0,00067	56,953	30,76	1004,0
	Type	Irradiance $\text{W/m}^2$	Correction Factor <sup>3)</sup>	Output mV	Temperature $^\circ\text{C}$	Calibration $\mu\text{V/W/m}^2$
Test Object	Si-mV-85-A	1004,0	0,996130	59,131	30,55	58,67

Test Equipment Irradiance Calibration

Manufacturer	Type	Serial No.	Calibration Certificate	Trace
Ingenieurbüro Mencke & Tegtmeier GmbH	Si-Ref mono PTB-1	02-20002-05-15309999	47109-PTB-18	PTB
Gantner Instruments	IDL100	191667	098220-02 D-K-15019-01-00	DKD
	ISM111	078743	098221-02 D-K-15019-01-00	DKD
OMEGA Engineering	IN510	9894	./. .	./. .

$$^1) \text{Irradiance} = \frac{\text{Output} * 1000}{\text{Calibration} * (1 + \text{Temperature Coefficient} * (\text{Temperature} - 25))}$$

$$^2) \text{Calibration} = \frac{\text{Output} * 1000 * \text{Correction Factor}}{\text{Irradiance}}$$

<sup>3)</sup> Individual calculated for each Calibration Process, must not be used for Outdoor Application.



**INGENIEURBÜRO**  
Mencke & Tegtmeier GmbH  
Meßgeräte für die Solartechnik

Schwarzer Weg 43A  
31789 Hameln, Germany  
www.ib-mut.de

#### Calibration Certificate Silicon Irradiance Sensor

Sensor Type: Si-mV-85-A  
Serial No.: 85-00205-17-19350115  
Comment:

#### Irradiance Calibration with Artificial Light in Comparison to a Reference Cell

Calibrated by: Huhnstock-Breuer  
Date / Time: 28.08.2019 14:00

	Type	Calibration $\mu\text{V/W/m}^2$	Temperature Coefficient $1/^\circ\text{C}$	Output mV	Temperature $^\circ\text{C}$	Irradiance <sup>1)</sup> $\text{W/m}^2$
Reference Cell	Si-Ref mono PTB-1	56,51	0,00067	56,953	30,76	1004,0
	Type	Irradiance $\text{W/m}^2$	Correction Factor <sup>3)</sup>	Output mV	Temperature $^\circ\text{C}$	Calibration $\mu\text{V/W/m}^2$
Test Object	Si-mV-85-A	1004,0	0,996047	58,457	30,67	58,00

#### Test Equipment Irradiance Calibration

Manufacturer	Type	Serial No.	Calibration Certificate	Trace
Ingenieurbüro Mencke & Tegtmeier GmbH	Si-Ref mono PTB-1	02-20002-05-15309999	47109-PTB-18	PTB
Gantner Instruments	IDL100	191667	098220-02 D-K-15019-01-00	DKD
	ISM111	078743	098221-02 D-K-15019-01-00	DKD
OMEGA Engineering	IN510	9894	./.	./.

$$^1) \text{Irradiance} = \frac{\text{Output} \cdot 1000}{\text{Calibration} \cdot (1 + \text{Temperature Coefficient} \cdot (\text{Temperature} - 25))}$$

$$^2) \text{Calibration} = \frac{\text{Output} \cdot 1000 \cdot \text{Correction Factor}}{\text{Irradiance}}$$

<sup>3)</sup> Individual calculated for each Calibration Process, must not be used for Outdoor Application.

Model 525 Series Certification/Calibration Information

(form PR-TRL-AL-02.docx)

The sensors go through the certified calibration process to document for record with  $\pm 1\%$  accuracy.

The recorded error readings for this sensor was: - 67 & 83

Calibration Date: 7-23-19 S/N: 81185-819

BY: VR

**NOTICE!!!**

During Shipment the tipping assembly has been secured to avoid possible damage to the pivot assembly. Lift off collection and remove rubber band from inside to release tipping mechanism before installation.

Calibration Certification – Digital Humidity- and Temperature Sensors

**SENSIRION**  
THE SENSOR COMPANY

## Calibration Certification

**Name and address of the manufacturer:** Sensirion AG  
Laubisruetistrasse 50  
CH-8712 Switzerland

**Description:** Digital Humidity- and Temperature Sensors

- |         |         |
|---------|---------|
| • SHT1x | • SHT2x |
| • SHT3x | • SHT7x |
| • SHTC1 | • SHTW1 |
| • STS21 | • STSC1 |

The above mentioned products are calibrated to meet the specifications according to the corresponding Sensirion data sheet. Each device is individually tested after its calibration.

Sensirion uses transfer standards for the calibration. These transfer standards are themselves subject to a scheduled calibration procedure. The calibration of the reference itself used for the calibration of the transfer standards is performed by an ISO/IEC 17025 accredited laboratory.

The accreditation body is full member of the International Laboratory Accreditation Cooperation ([www.ilac.org](http://www.ilac.org)). Calibration certificates issued by facilities accredited by a signatory to the ILAC Mutual Recognition Arrangement (MRA) are accepted by all signatories to the ILAC MRA.

This provides traceability of measurement to recognized national standards and to units of measurement realized at the "National Physical Laboratory" (NPL) or other recognized national standards laboratories like "Physikalisch-Technische Bundesanstalt" (PTB) or "National Institute of Standards and Technology" (NIST).

Staefa, November 2015



Stephan Weber,  
Director,  
Head of Quality Management, Sensirion AG



Volker Born  
Manager,  
Head of Quality Engineering, SensirionAG



## CERTIFICATE OF CALIBRATION AND TESTING

<b>SERIAL NUMBER:</b>	<b>WS00016669</b>
<b>CUSTOMER:</b>	<b>INTELTRONICS INSTRUMENT</b>
<b>P.O. NUMBER:</b>	<b>2293 4 DEC 18</b>
<b>INV NUMBER:</b>	<b>149890</b>
<b>MODEL:</b>	<b>03002 WIND SENTRY ANEM &amp; VANE WJ-BOX</b>

We hereby certify that the sensor serial number specified above has been inspected, tested, and found to comply with all process and material specifications established for the purpose of quality assurance of R. M. Young Company products. Engineering drawings, procedures, and specifications are maintained on file at our premises.

Standards established by R. M. Young Company for calibrating the measuring and test equipment used in controlling product quality are traceable to the National Institute of Standards and Technology (NIST).

Date of Certification: 25 Jan 2019

R. M. Young Company

Ed Chemosky  
Quality Assurance

**R. M. YOUNG COMPANY** 2801 Aero Park Drive, Traverse City Michigan 49686-9171 USA  
TEL: (231) 946-3980 FAX: (231) 946-4772 Email: met.sales@youngusa.com



1 (1)  
Certificate report no. H47-19330041

## CALIBRATION CERTIFICATE

**Instrument** PTB110 Barometer  
**Serial number** R3331021  
**Manufacturer** Vaisala Oyj, Finland  
**Calibration date** 14th August 2019

This instrument has been calibrated against a Vaisala PTB220 factory working standard. The Vaisala PTB220 is traceable to the National Institute of Standards and Technology (NIST, USA) via Vaisala Measurement Standards Laboratory (MSL). Vaisala MSL has been accredited by FINAS according to ISO/IEC 17025 standard.

At the time of shipment, the instrument described above was within its operating specifications.

### Calibration results

Reference pressure hPa	Calculated pressure hPa	Observed voltage Vdc	Correction* hPa	Uncertainty** hPa
510.3	510.2	0.043	0.1	± 0.15
610.0	610.0	0.459	0.0	± 0.15
700.0	700.0	0.833	0.0	± 0.15
809.8	809.8	1.291	0.0	± 0.15
900.0	900.0	1.666	0.0	± 0.15
999.9	999.9	2.083	0.0	± 0.15
1060.1	1060.1	2.334	0.0	± 0.15
1099.9	1099.9	2.500	0.0	± 0.15

\*To obtain the true pressure, add the correction to the barometer reading. Interpolated corrections may be used at intermediate readings of the scale of the barometer.

\*\*The calibration uncertainty given at 95 % confidence level,  $k = 2$

### Equipment used in calibration

<b>Type</b>	<b>Serial number</b>	<b>Calibration date</b>	<b>Certificate number</b>
HP34970A	17403	2019-06-12	1250-307103583
PTB220	PA 14018	2019-03-21	K008-C00955

### Ambient conditions

Humidity:  $37 \pm 5$  %RH

Temperature:  $22 \pm 2$  °C

Pressure:  $1004 \pm 20$  hPa

  
Technician

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Doc214685-B

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