Monthly Solar Irradiation

Wadelai
Uganda

June 2020

Document No: GSAMSR-102-202006-v02

Client:	World Bank
Site name:	Wadelai
Geographical coordinates:	02° 43' 33.46" N
	31° 23' 25.45" E
Elevation above sea level:	644 m
Slope inclination:	0°
Slope azimuth:	195° South

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Overview

A monthly summary of solar irradiation data as recorded by the on-site meteorological measurement station (shown in Figure 1) is presented in this report. GeoSUN Africa commissioned the station on 22 January 2020 and data is provided from 01 February 2020. The station is located near Wadelai in Uganda. GeoSUN offers further services by performing data quality checks, a scheduled site visit after six months and monitoring of the instrument cleaning. Global Horizontal Irradiation (GHI) and Diffused Horizontal Irradiation (DHI) data is provided together with meteorological data.

Figure 1: Wadelai on-site solar and meteorological measurement station

Data Fields

Recorded ground data has a minute temporal resolution. Hourly, daily and monthly data is derived from minute data. Noteworthy data is identified by a red block on the relevant graph and clarified in Section 6. Table 1 defines the fields used in this report.

Field	Instrument	Measurement
GHI (1)	Thermopile Pyranometer (Kipp & Zonen CMP10)[1]	Global Horizontal Irradiation
GHI (2)	Thermopile Pyranometer (Kipp & Zonen CMP10)[1]	Global Horizontal Irradiation
GHI (1) vs (2)	GHI Difference Calculated[2]	Global Horizontal Irradiation Difference
GHI (SAT)	Satellite Derived (Solargis)	Global Horizontal Irradiation
GHI (SGLT)	GHI Long-Term Satellite Derived (Solargis)[3]	Global Horizontal Irradiation
GHI (1) vs (SAT)	GHI Difference Calculated[2]	Global Horizontal Irradiation Difference
DHI (1)	Solar Sensor (Delta-T SPN1)[4]	Diffused Horizontal Irradiation
DHI (SAT)	Satellite Derived (Solargis)	Diffused Horizontal Irradiation
DHI (SGLT)	DHI Long-Term Satellite Derived (Solargis)[3]	Diffused Horizontal Irradiation
DHI (1) vs (SAT)	DHI Difference Calculated[2]	Diffused Horizontal Irradiation Difference
GTI (Clean)	Silicon Irradiance Sensor (Ingenieurbüro Si-mV-85)	Global Tilted Irradiation (Cleaned)[5]
GTI (Soil)	Silicon Irradiance Sensor (Ingenieurbüro Si-mV-85)	Global Tilted Irradiation (Soiled)[5]
GTI (Clean) vs (Soil)	GTI Difference Calculated	Cleaned-Soiled GTI Difference
GTI (Monthly)	Silicon Irradiance Sensor (Ingenieurbüro Si-mV-85)	Global Tilted Irradiation (Cleaned Monthly)[5]
GTI (Clean) vs (Monthly)	GTI Difference Calculated	Cleaned-Monthly GTI Difference
Temperature	Thermometer (Campbell Scientific model CS215)	Ambient Air Temperature
Temperature (SAT)	Satellite Derived (Solargis)	Ambient Air Temperature
Humidity	Hygrometer (Campbell Scientific model CS215)	Relative Humidity
Pressure	Barometer (Vaisala PTB110)	Barometric Pressure
Wind Speed	Anemometer (RM Young 03002)	Wind Speed (measured at 3 m)
Wind Direction	Wind Vane (RM Young 03002)	Wind Direction (measured at 3 m)[6]
Rain	Rain Gauge (Texas Electronics TR-525I)	Rain
Cleaning	Push Button	Button to be pressed on cleaning event
NaN	Numerical Value Not Available	Not a Number

[1] High accuracy thermopile pyranometer (ISO 9060 secondary standard)

[2] See chapter 3 for calculation

[3] Long-term satellite derived data averaged over multiple years, see chapter 4

[4] Thermopile pyranometer

[5] Measuring soiling on site, tilted at 10° South

[6] The direction 0/360° indicates North (with 90° East)

Table 1: Nomenclature

1 Hourly Solar Irradiation Data

Figure 1.1 presents the hourly solar irradiation data. See Section 6 for further comments on the evaluation of this data.

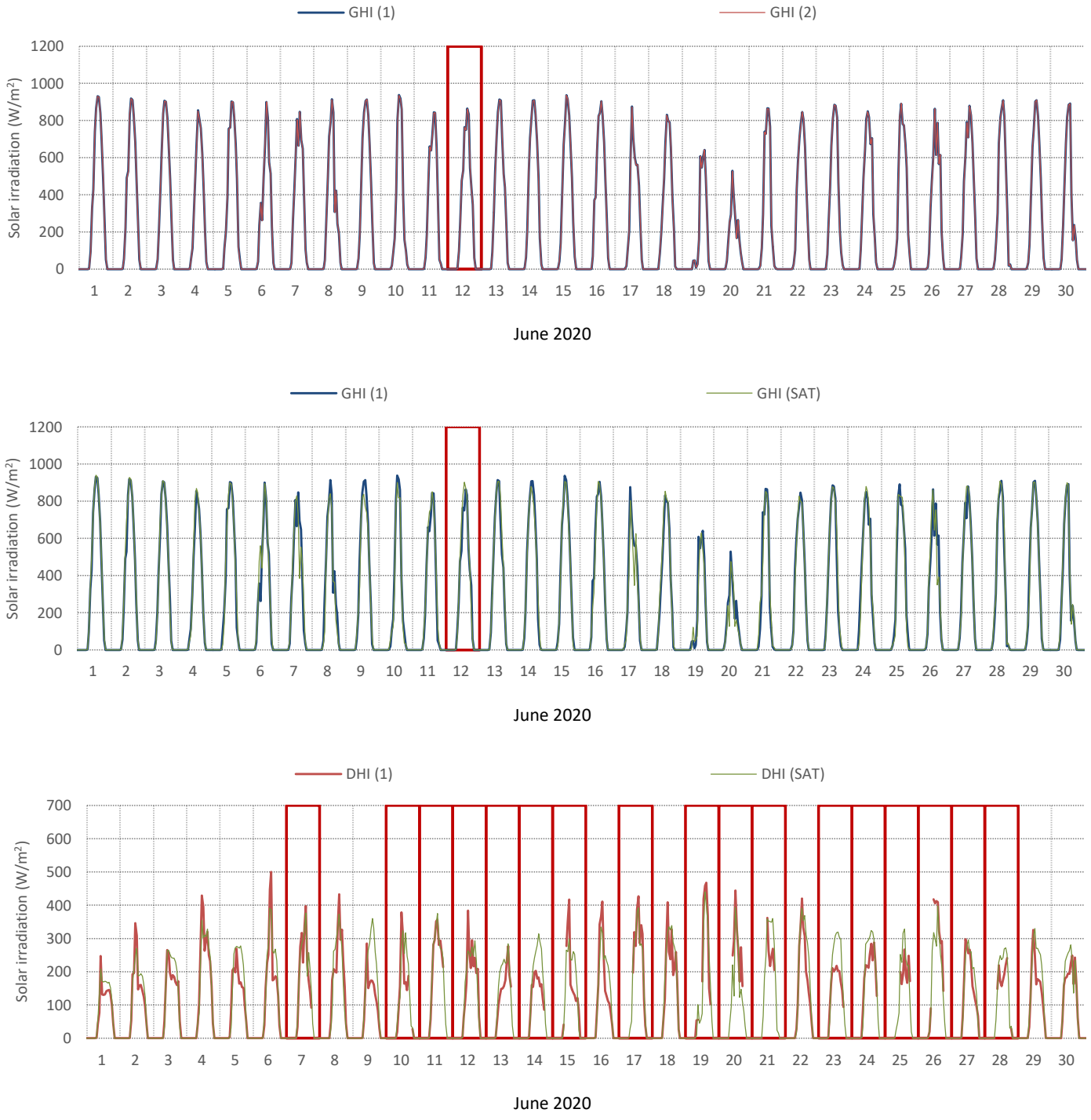


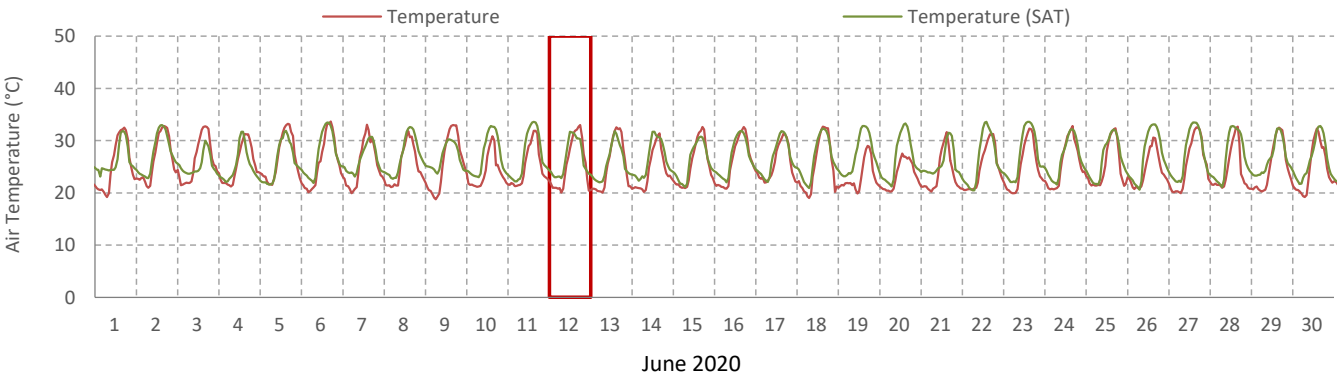
Figure 1.1 Hourly solar irradiation data

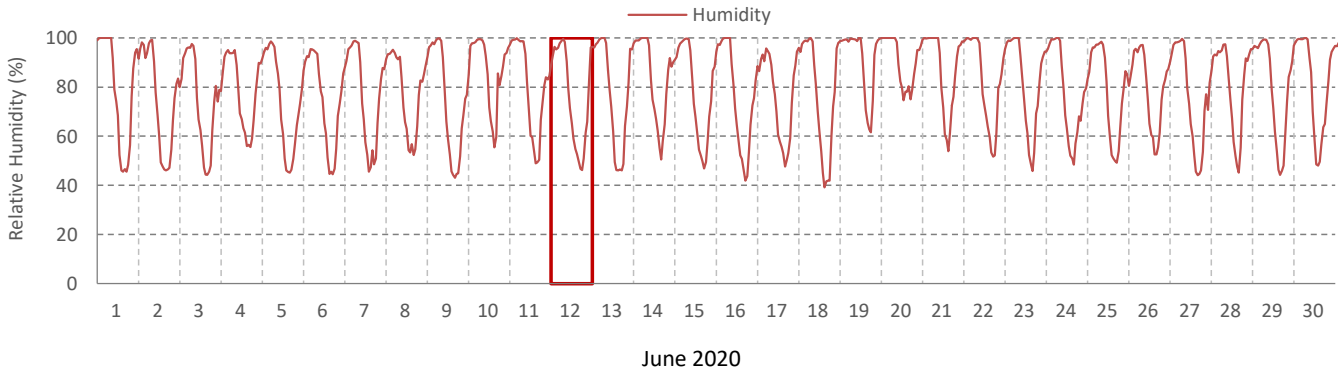
2 Hourly and Daily Meteorological Data

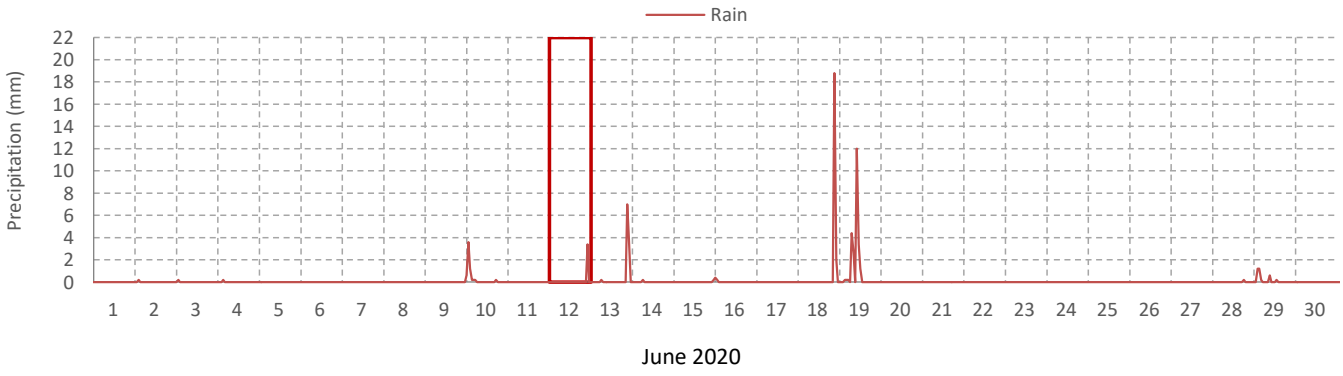
Table 2.1 presents the daily meteorological data. Figure 2.1 presents the hourly meteorological data.

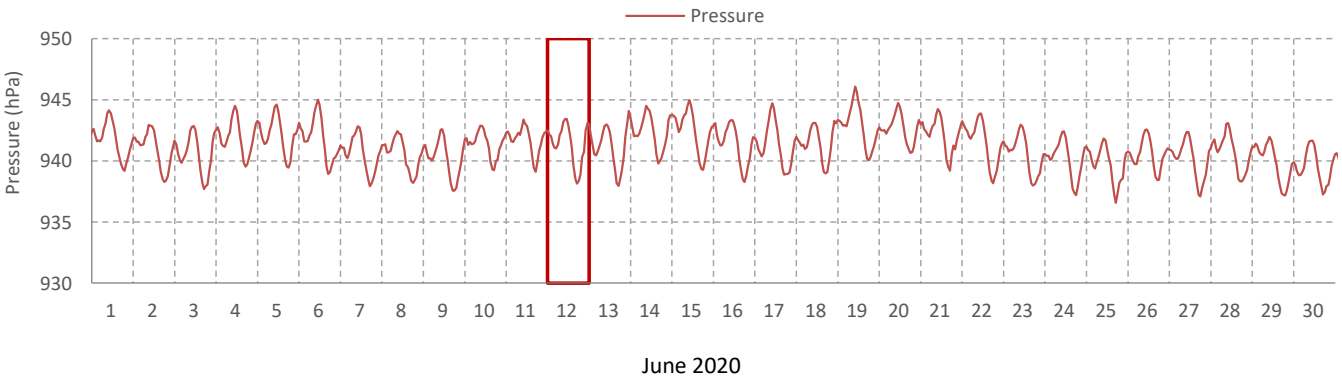
Day	Temperature Degree Celsius	Temperature (SAT) Degree Celsius	Rain mm
01-June-20	25.40	26.20	0.00
02-June-20	26.49	27.43	0.20
03-June-20	26.26	25.20	0.20
04-June-20	25.48	25.15	0.20
05-June-20	26.49	25.99	0.00
06-June-20	25.87	27.35	0.00
07-June-20	25.39	26.27	0.00
08-June-20	25.08	27.12	0.00
09-June-20	25.78	26.67	0.60
10-June-20	23.95	27.01	5.60
11-June-20	25.04	27.19	0.00
12-June-20	25.39	26.48	3.40
13-June-20	25.09	25.65	11.20
14-June-20	24.40	26.41	0.20
15-June-20	25.34	25.88	0.60
16-June-20	26.01	26.76	0.20
17-June-20	25.50	26.60	0.00
18-June-20	25.09	26.54	20.80
19-June-20	23.14	27.25	24.20
20-June-20	23.43	26.58	0.00
21-June-20	23.69	25.70	0.00
22-June-20	24.80	26.30	0.00
23-June-20	24.84	27.24	0.00
24-June-20	25.54	26.54	0.00
25-June-20	24.98	26.44	0.00
26-June-20	24.36	26.97	0.00
27-June-20	25.43	27.26	0.00
28-June-20	24.22	26.90	0.20
29-June-20	25.05	26.56	3.40
30-June-20	24.55	26.25	0.00
Average	25.07	26.53	
Maximum	26.49	27.43	24.20
Minimum	23.14	25.15	0.00
Total			71.00

Table 2.1 Daily meteorological data









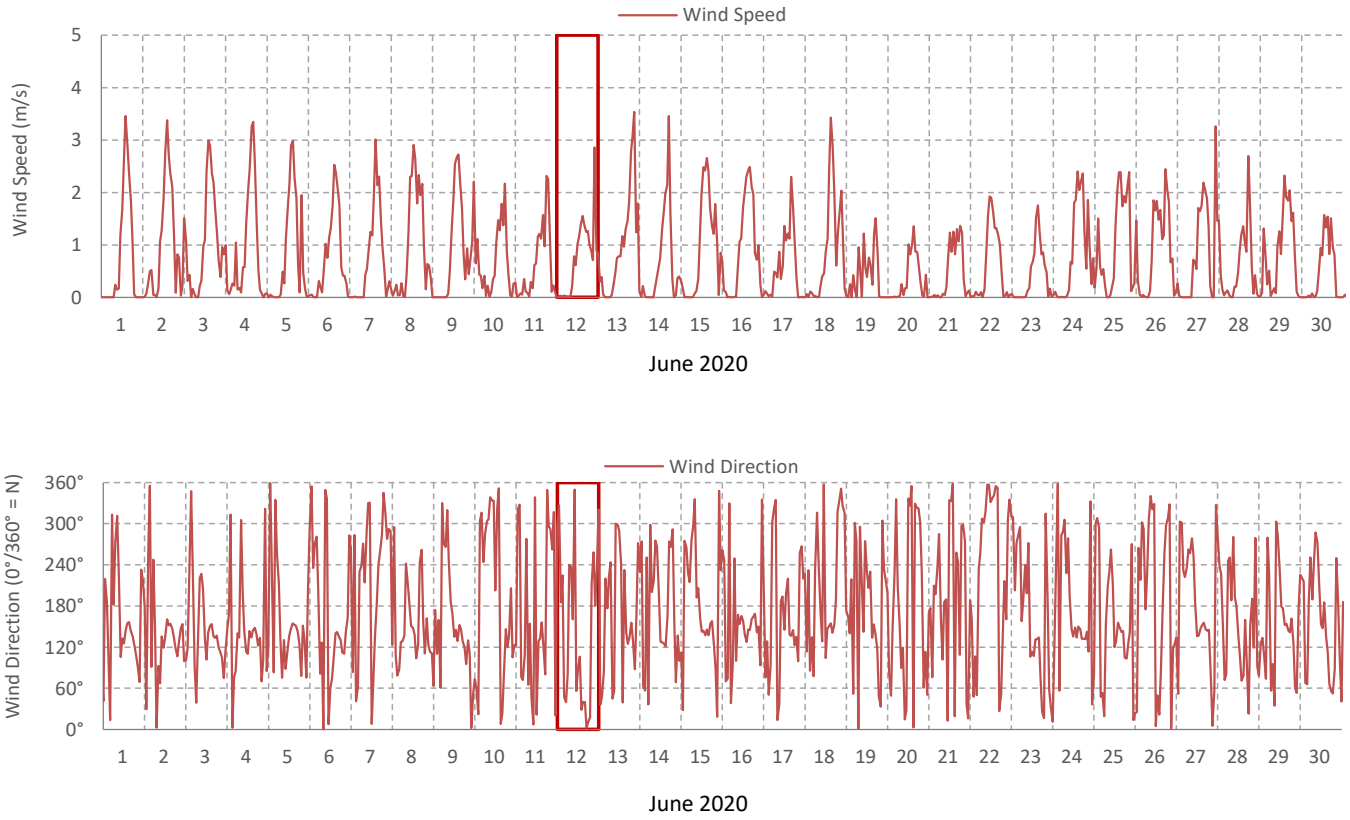


Figure 2.1 Hourly meteorological data

3 Daily Solar Irradiation Data

Table 3.1 presents the daily GHI solar irradiation data. The daily percentage difference between GHI (1) and GHI (2) as well as GHI (1) and GHI (SAT) is calculated and also presented. On overcast days the difference between the GHI values will likely be large due to low irradiation values. The difference is calculated as follows:

$$\text{GHI (1) vs (2)} = 100 \times \left(\frac{\text{GHI (1)} - \text{GHI (2)}}{\text{GHI (1)}}\right) \qquad \text{GHI (1) vs (SAT)} = 100 \times \left(\frac{\text{GHI (1)} - \text{GHI (SAT)}}{\text{GHI (1)}}\right)$$

Day	GHI (1) kWh/m^2/day	GHI (2) kWh/m^2/day	GHI (SAT) kWh/m^2/day	GHI (1) vs (2) %	GHI (1) vs (SAT) %
01 June '20	6.63	6.63	6.80	0.07	-2.53
02 June '20	6.25	6.25	6.54	0.02	-4.68
03 June '20	6.24	6.24	6.15	0.06	1.53
04 June '20	5.35	5.35	5.51	0.04	-2.97
05 June '20	6.17	6.17	6.16	-0.02	0.26
06 June '20	5.14	5.13	5.55	0.01	-8.12
07 June '20	5.54	5.53	5.48	0.17	1.00
08 June '20	5.28	5.27	4.70	0.30	11.03
09 June '20	6.34	6.34	5.92	0.04	6.70
10 June '20	4.87	4.86	4.51	0.15	7.47
11 June '20	5.48	5.47	5.75	0.25	-4.89
12 June '20	5.96	5.95	6.25	0.19	-4.86
13 June '20	6.23	6.22	6.46	0.21	-3.69
14 June '20	6.35	6.34	6.26	0.05	1.42
15 June '20	6.20	6.21	6.02	-0.04	2.94
16 June '20	6.36	6.35	6.08	0.02	4.41
17 June '20	4.97	4.96	4.42	0.14	11.13
18 June '20	5.49	5.47	5.79	0.31	-5.50
19 June '20	3.48	3.49	3.24	-0.12	7.06
20 June '20	2.65	2.64	2.26	0.33	14.73
21 June '20	4.77	4.76	4.82	0.23	-1.15
22 June '20	5.70	5.69	5.54	0.17	2.83
23 June '20	5.61	5.60	5.91	0.21	-5.29
24 June '20	5.91	5.90	5.80	0.20	1.77
25 June '20	5.52	5.52	5.37	-0.02	2.74
26 June '20	5.22	5.21	5.14	0.14	1.52
27 June '20	6.04	6.04	6.17	0.05	-2.08
28 June '20	5.48	5.47	5.65	0.12	-3.16
29 June '20	6.12	6.12	6.01	0.04	1.79
30 June '20	5.01	5.00	5.14	0.33	-2.45
Average	5.55	5.54	5.51	0.13*	4.39*
Maximum	6.63	6.63	6.80	0.33	14.73
Minimum	2.65	2.64	2.26	0.01	0.26

*Average of absolute values of daily percentage difference, representing data comparison on daily level (will differ from percentage difference of averaged GHI values, which represents monthly data comparison).

Table 3.1 Daily solar irradiation data

Table 3.2 presents the daily DHI solar irradiation data. The daily percentage difference between DHI (1) and DHI (SAT) is calculated and also presented. On overcast days the difference between the DHI values will likely be large due to low irradiation values. The difference is calculated as follows:

$$\text{DHI (1) vs (SAT)} = 100 \times \left(\frac{\text{DHI (1)} - \text{DHI (SAT)}}{\text{DHI (1)}} \right)$$

Day	DHI (1) kWh/m^2/day	DHI (SAT) kWh/m^2/day	DHI (1) vs (SAT) %
01 June '20	1.47	1.72	-17.01
02 June '20	1.97	2.05	-3.95
03 June '20	2.04	2.31	-12.76
04 June '20	2.82	2.67	5.30
05 June '20	1.95	2.45	-25.85
06 June '20	2.50	2.70	-7.89
07 June '20	2.40	2.60	-8.65
08 June '20	2.65	2.51	5.44
09 June '20	1.69	2.69	-59.39
10 June '20	1.65	2.10	-27.75
11 June '20	2.55	2.78	-9.10
12 June '20	2.43	2.43	0.00
13 June '20	1.76	2.23	-26.50
14 June '20	1.67	2.47	-48.07
15 June '20	1.98	2.31	-17.06
16 June '20	2.20	2.43	-10.74
17 June '20	2.70	2.70	-0.11
18 June '20	2.53	2.81	-11.01
19 June '20	2.25	2.26	-0.65
20 June '20	NaN	-	
21 June '20	NaN	-	
22 June '20	2.45	2.91	-18.58
23 June '20	1.90	2.65	-39.55
24 June '20	2.34	2.74	-17.26
25 June '20	1.60	2.07	-29.34
26 June '20	2.80	2.60	7.14
27 June '20	2.15	2.34	-8.76
28 June '20	1.55	2.20	-41.46
29 June '20	1.96	2.51	-27.65
30 June '20	2.06	2.31	-11.99
Average	2.14	2.45	17.82*
Maximum	2.82	2.91	-59.39
Minimum	1.47	1.72	0.00

*Average of absolute values of daily percentage difference, representing data comparison on daily level (will differ from percentage difference of averaged DHI values, which represents monthly data comparison).

Table 3.2 Daily solar irradiation data

Table 3.3 presents the daily GTI data. On overcast days the difference between the sensors will likely be large due to low irradiation values. The daily difference between GTI (Clean) and GTI (Soil) as well as GTI (Clean) and GTI (Monthly) is also calculated and presented. The difference is calculated as follows:

$$\text{GTI (Clean) vs (Soil)} = 100 \times \left(\frac{\text{GTI (Clean)} - \text{GTI (Soil)}}{\text{GTI (Clean)}}\right) \qquad \text{GTI (Clean) vs (Monthly)} = 100 \times \left(\frac{\text{GTI (Clean)} - \text{GTI (Monthly)}}{\text{GTI (Clean)}}\right)$$

Day	GTI (Clean) kWh/m^2/day	GTI (Soil) kWh/m^2/day	GTI (Monthly) kWh/m^2/day	GTI (Clean) vs (Soil) %	GTI (Clean) vs (Monthly) %
01 June '20	5.85	5.80	5.84	0.83	0.13
02 June '20	5.58	5.54	5.57	0.78	0.25
03 June '20	5.62	5.58	5.60	0.74	0.40
04 June '20	4.87	4.83	4.84	0.84	0.69
05 June '20	5.57	5.50	5.52	1.18	0.90
06 June '20	4.66	4.60	4.60	1.30	1.20
07 June '20	5.00	4.92	4.93	1.61	1.40
08 June '20	4.85	4.75	4.77	1.87	1.54
09 June '20	5.66	5.56	5.56	1.84	1.77
10 June '20	4.51	4.47	4.49	0.78	0.36
11 June '20	5.01	4.96	4.99	0.92	0.41
12 June '20	5.30	5.25	5.27	0.90	0.51
13 June '20	5.54	5.49	5.52	0.96	0.40
14 June '20	5.65	5.60	5.63	0.84	0.34
15 June '20	5.59	5.55	5.57	0.80	0.45
16 June '20	5.66	5.61	5.63	0.88	0.56
17 June '20	4.50	4.46	4.47	0.88	0.69
18 June '20	4.94	4.88	4.89	1.24	0.95
19 June '20	3.18	3.17	3.17	0.40	0.50
20 June '20	2.60	2.58	2.59	0.97	0.56
21 June '20	4.39	4.34	4.36	1.09	0.76
22 June '20	5.12	5.06	5.07	1.12	0.93
23 June '20	5.06	4.99	5.01	1.38	0.97
24 June '20	5.29	5.21	5.23	1.51	1.13
25 June '20	5.02	4.94	4.93	1.53	1.87
26 June '20	4.77	4.68	4.66	1.86	2.25
27 June '20	5.38	5.27	5.25	2.03	2.51
28 June '20	5.01	4.92	4.90	1.88	2.21
29 June '20	5.47	5.41	5.42	1.09	0.92
30 June '20	4.59	4.52	4.54	1.56	1.10
Average	5.01	4.95	4.96	1.19*	0.96*
Maximum	5.85	5.80	5.84	2.03	2.51
Minimum	2.60	2.58	2.59	0.40	0.13

*Average of absolute values of daily percentage difference, representing data comparison on daily level (will differ from percentage difference of averaged reference cell values, which represents monthly data comparison).

Table 3.3 Daily GTI data

Figure 3.1 presents the daily solar irradiation data.

Figure 3.1 Daily solar irradiation data

Figure 3.2 presents the daily solar irradiation data (GTI) for the solar sensors measuring the effect of soiling on site. Figure 3.3 presents the difference between the cleaned and the monthly cleaned sensor.

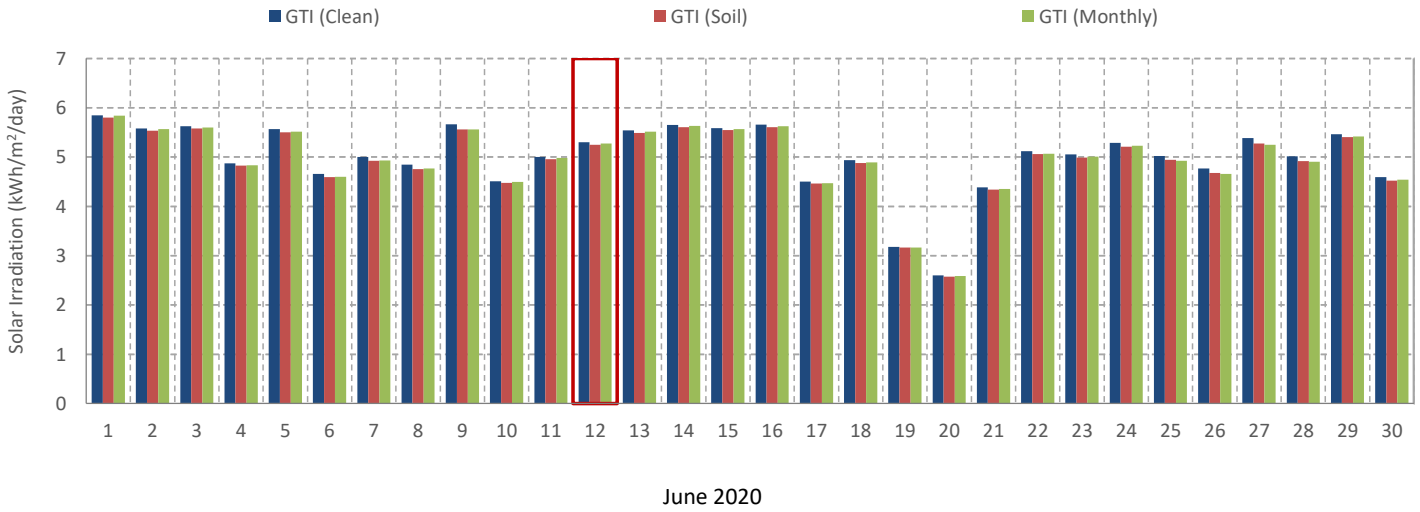


Figure 3.2 GTI daily solar irradiation data

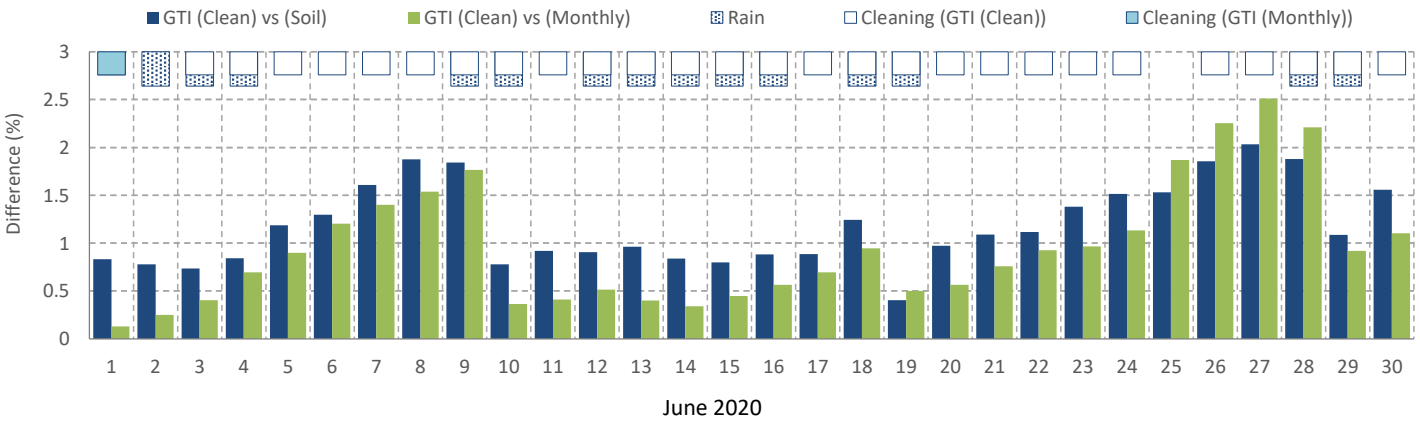


Figure 3.3 GTI daily solar irradiation difference

4 Monthly Solar Irradiation Data

Table 4.1 presents the monthly sum of solar irradiation data as well as the accumulated annual value at time of report. Figure 4.1 presents the monthly sum of solar irradiation data as well as the average daily solar irradiation data. For more information on previous month's data see relevant month's report.

Month	GHI (1) kWh/m^2/month	GHI (2) kWh/m^2/month	GHI (SAT) kWh/m^2/month	GHI (SGLT) kWh/m^2/month	DHI (1) kWh/m^2/month	DHI (SAT) kWh/m^2/month	DHI (SGLT) kWh/m^2/month
February '20	167	167	178	185	66	77	74
March '20	175	174	183	191	77	83	78
April '20	186	185	184	179	67	71	71
May '20	182	182	179	184	61**	67**	67
June '20	166	166	165	164	64**	73**	70
Annual*	877	875	889	903	336	371	359

*Year to date sum (includes 5 months of measurement).
**Available day data used

Table 4.1 Monthly sum of irradiation

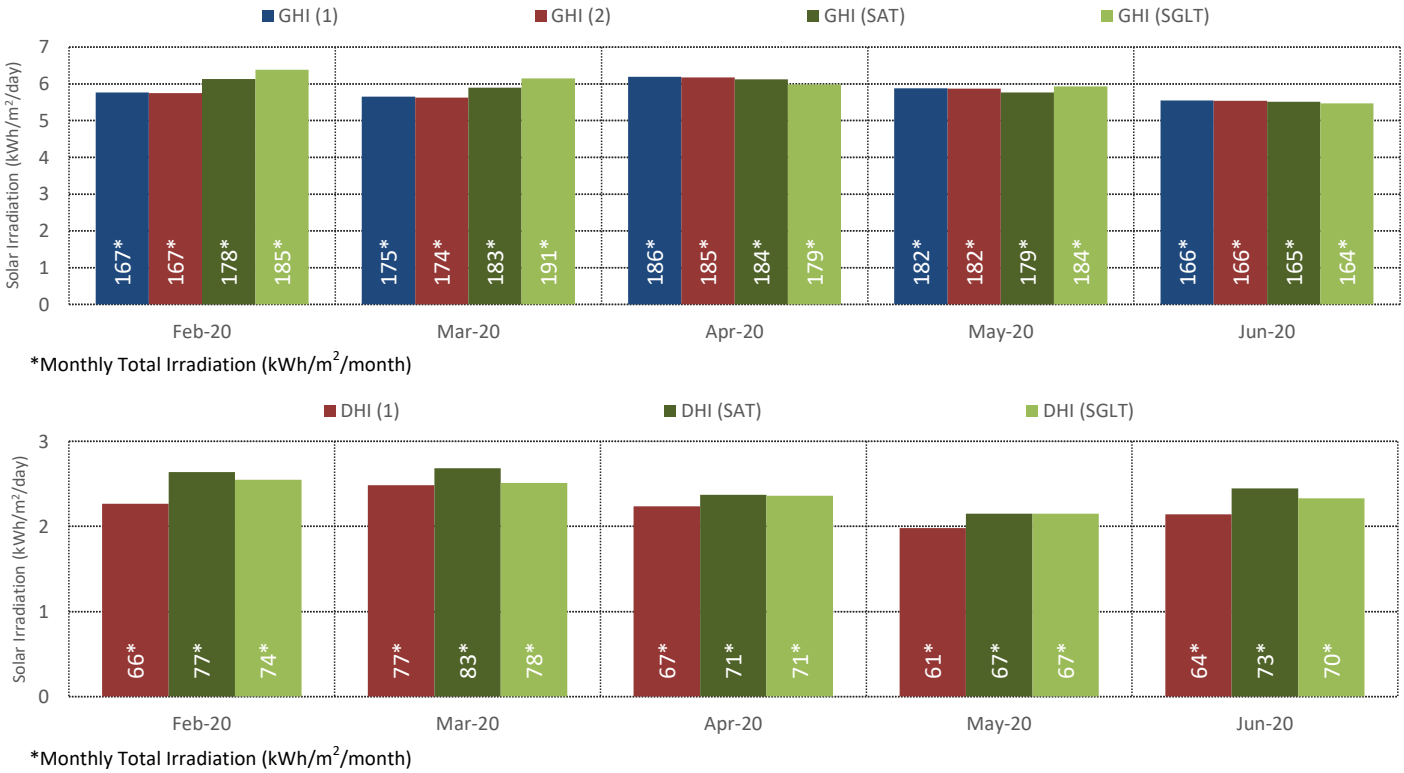


Figure 4.1 Monthly solar irradiation data

Table 4.2 presents the monthly GHI solar irradiation data. For more information on previous month's data see relevant month's report.

Month	**GHI (1)** kWh/m^2/day	**GHI (2)** kWh/m^2/day	**GHI (SAT)** kWh/m^2/day	**GHI (1) vs (2)** %	**GHI (1) vs (SAT)** %
February '20	5.77	5.74	6.13	0.43	-6.29
March '20	5.65	5.63	5.90	0.41	-4.40
April '20	6.20	6.18	6.13	0.29	1.13
May '20	5.88	5.87	5.77	0.15	1.85
June '20	5.55	5.54	5.51	0.12	0.59
Average	5.81	5.79	5.89	*	*
Maximum	6.20	6.18	6.13	0.43	-6.29
Minimum	5.55	5.54	5.51	0.12	0.59

*See Table 4.3

**Available day data used

Table 4.2 Monthly solar irradiation data

Table 4.3 presents the overall percentage difference between the two pyranometers (GHI (1) vs (2)) as well as GHI (1) and satellite derived data (GHI (1) vs (SAT)) for the measurement campaign up to date of report. The average of the daily values are used.

Duration Months	**GHI (1)** kWh/m^2/day	**GHI (2)** kWh/m^2/day	**GHI (SAT)** kWh/m^2/day	**GHI (1) vs (2)** %	**GHI (1) vs (SAT)** %
5	5.81	5.79	5.89	0.28	-1.38

Table 4.3 Solar irradiation data comparison

Table 4.4 presents the monthly DHI solar irradiation data. For more information on previous month's data see relevant month's report.

Month	**DHI (1)** kWh/m^2/day	**DHI (SAT)** kWh/m^2/day	**DHI (1) vs (SAT)** %
February '20	2.27	2.64	-16.51
March '20	2.49	2.69	-8.05
April '20	2.24	2.37	-6.00
May '20	1.98**	2.15**	-8.58
June '20	2.14**	2.45**	-14.22
Average	2.22	2.46	*
Maximum	2.49	2.69	-16.51
Minimum	1.98	2.15	-6.00

*See Table 4.5

**Available day data used

Table 4.4 Monthly solar irradiation data

Table 4.5 presents the overall percentage difference between the ground measured DHI and the satellite derived DHI (DHI (1) vs (SAT)) for the measurement campaign up to date of report. The average of the daily values are used.

Duration Months	**DHI (1)** kWh/m^2/day	**DHI (SAT)** kWh/m^2/day	**DHI (1) vs (SAT)** %
5	2.22	2.46	-10.65

Table 4.5 Solar irradiation data comparison

Table 4.6 presents the monthly GTI data. The value of this table is not in comparing whether the results of the individual instruments are close to each other, but rather the percentage difference which is indicative of the effect of soiling on the site. For more information on previous month's data see relevant month's report.

Month	GTI (Clean) kWh/m^2/day	GTI (Soil) kWh/m^2/day	GTI (Monthly) kWh/m^2/day	GTI (Clean) vs (Soil) kWh/m^2/day	GTI (Clean) vs (Monthly) kWh/m^2/day
February '20	5.91	5.71	5.75	3.41	2.66
March '20	5.58	5.48	5.52	1.78	1.12
April '20	5.89	5.84	5.86	0.74	0.41
May '20	5.38	5.36	5.36	0.46	0.34
June '20	5.01	4.95	4.96	1.19	0.96
Average	5.55	5.47	5.49	*	*
Maximum	5.91	5.84	5.86	3.41	2.66
Minimum	5.01	4.95	4.96	0.46	0.34

*See Table 4.7

**Available day data used

Table 4.6 Monthly GTI data

Table 4.7 presents the overall percentage difference between the two solar irradiance sensors for the measurement campaign up to date of report. The average of the daily values are used.

Duration Months	GTI (Clean) kWh/m^2/day	GTI (Soil) kWh/m^2/day	GTI (Monthly) kWh/m^2/day	GTI (Clean) vs (Soil) kWh/m^2/day	GTI (Clean) vs (Monthly) kWh/m^2/day
5	5.55	5.47	5.49	1.54	1.11

Table 4.7 GTI data comparison

5 Station Maintenance

The cleaning events for this month is shown in Figure 5.1 (28 cleaning events were recorded).

The maximum period without cleaning was 1 day. This is considered acceptable and the cleaning was done well for this month. Irradiation measurement during a cleaning event will most likely be affected for a couple of minutes due to shading. The cleaner has been instructed to clean one of the solar irradiance sensors (GTI (Monthly)) once a month, which was done on 1 June.

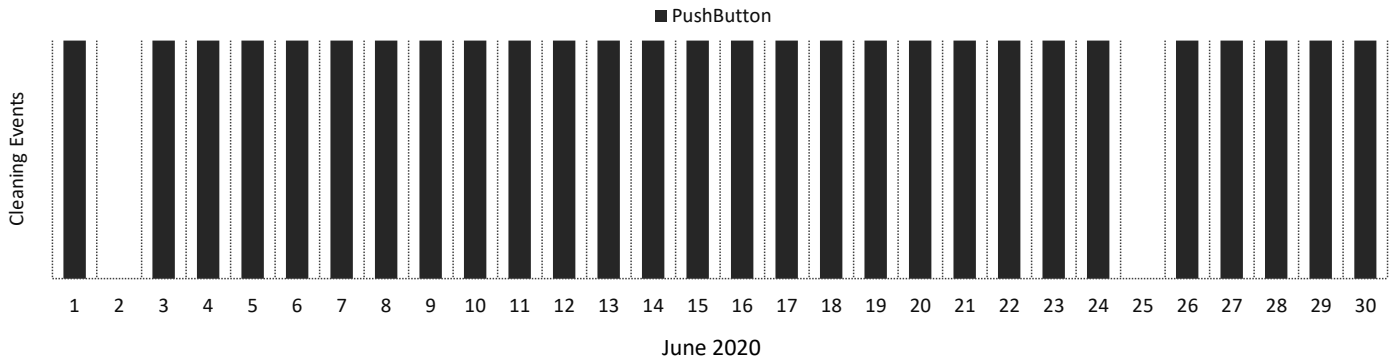


Figure 5.1: Cleaning events

6 Summary

The station is operational, the logger is running and communications are active.

The primary quality check for the GHI measurement is the comparison between the two thermopile pyranometers (GHI (1) and GHI (2)) and from this it can be concluded that the GHI data quality is good.

The monthly average of GHI (1) and GHI (2) differ with 0.12 % for the month of June 2020 and has a 0.28 % difference over the full measurement period (01 February 2020 to date).

The monthly average of GTI (Clean) and GTI (Soil) differ with 1.19 % for the month of June 2020 and has a 1.54 % difference over the full measurement period (01 February 2020 to date).

The monthly average of GTI (Clean) and GTI (Monthly) differ with 0.96 % for the month of June 2020 and has a 1.11 % difference average over the full measurement (01 February 2020 to date).

Throughout the month a total of 2 minutes of data was removed either due to program upgrades, station restart or failing quality checks, this occurred on the following day:
12 June 2020.
This is indicated with NaN values in the minute data file and a red block on the applicable graph in this report.

The SPN1 pyranometer measuring DHI (1) recorded faulty values during some early mornings and late afternoons throughout June. These values were removed and indicated with a red block on the applicable graph in this report.
Daily values are removed from the report on days where the amount of minute values available are deemed too few to calculate a representative daily value.

Water residue affected early morning irradiation measurements on the following day:
1 June 2020.