Assessment of Global Horizontal Irradiance in South Africa.

Brighton Mabasa, **Henerica Tazvinga, Nosipho Zwane, Joel Botai and Lucky Ntsangwane**

South African Weather Services, Cnr Olievenhoutbosch and Ribbon Grass Streets, Centurion, 0157, South Africa

Phone: +27-12-367 6088; Fax: +27-12-367 6189; Email: Brighton.Mabasa@weathersa.co.za;
Henerica.Tazvinga@weathersa.co.za; Nosipho.Zwane@weathersa.co.za ;Joel.Botai@weathersa.co.za;
Lucky.Ntsangwane@weathersa.co.za

Abstract

South African Weather Service (SAWS) manages a radiometric network of 13 stations located in six climatic zones of South Africa since 2013. The data collected from the network enable quantification of the potential contribution of the solar energy resource, improvement and validation of satellites as well as the development and verification of empirical models. Quality control (QC) assessment of SAWS data was conducted using procedures outlined by the Baseline Surface Radiation Network (BSRN). For all the stations, on average 98.25% of the global solar radiation (GHI) data were classified as good quality data. The annual average daily GHI ranged from 186 W/m^2 to 265 W/m^2 with consistently higher values in the arid interior climatic zone and lower values in the subtropical coastal climatic zone. Validation of results showed that Satellite Application Facility on Climate Monitoring (CM SAF) data were closer to the observation data with an overall mean absolute deviation (MAD) of 11.81 W/m^2 and National Aeronautics and Space Administration (NASA), Surface Meteorology and Solar Energy (SSE) had an overall MAD of 19.59 W/m^2.The solar resource's monthly, seasonal and annual characteristics analysed for different stations provide information that has a strong influence on the technical and economic evaluation of solar energy technologies. Validated satellite data sets are important in providing additional long term data sets for areas and times with no in-situ solar radiation observations.

Key words: Incident radiative flux; Radiometric network; Solar energy resource; Baseline Solar Radiation Network; Global Horizontal Irradiance; Satellite, Validation.

1. Introduction and Theory

1.1 Global Horizontal Irradiance (GHI)

Solar radiation is the electromagnetic radiation emitted by the sun [1]. GHI is the electromagnetic radiation that reaches the earth's surface after passing through the atmosphere and it is the sum of direct normal irradiance (DNI) which is the incident radiative flux on the surface without interacting with the atmosphere and diffuse irradiance (DIF) which is as a result of the scattering of radiation by the atmospheric constituents [2]. GHI covers the spectral range between 250 and 3000 nm [3]. At SAWS, GHI is measured with an unshaded secondary standard Kipp & Zonen pyranometer (CM11) with a hemispherical view that is mounted horizontally. The irradiance values are measured in W/m^2 and calculated by dividing voltage by the sensors' calibration factor. The pyranometers are mounted on a Kipp & Zonen SOLYS 2 sun-tracker which is mounted on a cage housing the data logger, batteries and some electronic devices, raising the solar radiation sensors to a standard height of 2 meters above sea level as shown in Figure 1.

Figure 1. Configuration of a SAWS radiometric station with an unshaded pyranometer at the centre.

1.2. Significance of GHI measurement

Solar radiation measurement is important because solar radiation resource data is the foundation of information for the development of solar energy technologies [4]. Accurate knowledge of the strength of the sun is important for the technical and economic evaluation of solar energy technologies, therefore, obtaining true solar measurements is important in assessing the available solar resource at a particular location [5]. Reliable solar measurements are also important in the development of empirical models to predict and forecast the availability of solar energy at other locations [6]. Satellite derived data is also critical for better understanding wider coverage of solar radiation and can also be validated using high quality ground data [7]. According to [8] the main aim of solar radiation measurement is to provide investment grade bankable radiation data to the solar industry. It is important to provide reliable and accurate data sets and their related characteristics, that is information for different locations and temporal resolutions (i.e. hourly, daily, monthly, seasonal and annual statistics). This paper contributes towards the provision of reliable solar radiation data to the energy industry, project developers, decision makers in the financing institutions, policy makers and also to the scientific community.

1.3. Data acquisition, station maintenance and sensor calibration

GHI data from 13 radiometric stations located in six climatological regions of South Africa as shown in Table 1 were acquired using a Campbell Scientific CR1000 data logger. The sampling rate was 5 seconds and the mean, maximum, minimum and standard deviation values were recorded every minute. Solar radiation sensors were connected on the differential inputs of the CR1000 to minimise measurement offsets.

Station	Latitude	Longitude	Altitude (m)	Data coverage	Climatic Zone
Prieska	-29.68	22.71	989	2013-09 to 2015-08	Arid Interior
Upington	-28.48	21.12	848	2014-02 to 2019-03	Arid Interior
Deaar	-30.67	23.99	1284	2014-02 to 2019-03	Cold Interior
Irene	-25.91	28.21	1524	2014-02 to 2019-03	Temperature Interior
Nelspruit	-25.39	31.1	870	2014-02 to 2019-03	Hot Interior
Mahikeng	-25.81	25.54	1289	2014-08 to 2019-03	Temperature Interior
Mthatha	-31.55	28.67	744	2014-08 to 2019-03	Subtropical Coastal
Bethlehem	-28.25	28.33	1688	2015-01 to 2019-03	Cold Interior
Cape Point	-34.35	18.48	86	2015-02 to 2019-03	Temperature Coastal
George	-34.01	22.38	192	2015-01 to 2019-03	Temperature Coastal
Durban	-29.61	31.11	91	2015-03 to 2019-03	Subtropical Coastal
Polokwane	-23.86	29.45	1233	2015-03 to 2019-02	Temperature Interior
Thohoyandou	-23.08	30.38	619	2015-03 to 2017-10	Hot Interior

Table 1. SAWS radiometric station location (latitude, longitude, altitude, data coverage and climatic zone).

Maintenance, inspection and cleaning activities at these stations are conducted on a bi-weekly basis. These involve the dusting of the sensor dome using a soft lint-free cloth and distilled water to remove any deposits on the domes and optical windows, and checking of the spirit levels in the pyranometers (i.e. must be level horizontally), all the cables and any damages. Desiccants are also replaced within 6 months. Cleaning and inspection times are recorded and kept as metadata.

A radiometer measures radiant energy, however, its sensitivity reduces with time necessitating periodic calibration of the instrument [9]. Frequent sensor calibration remains the best practice to ensure that high quality data are collected and is the standard operating procedure in radiation monitoring networks [10]. For this work, all operational field pyranometers were calibrated by the manufacturer and they are traceable to the World Radiometric Reference (WRR) based on International Pyrheliometer Comparison (IPC) factors. This means that SAWS measurements meet the international criteria for accurate and scientifically valid radiometric data.

2. Data and Analysis Method

GHI data at one minute intervals collected during the periods shown in Table 1 from 13 SAWS solar radiometric stations were subjected to quality check procedures based on Meteorological Organisation (WMO)'s BSRN QC standards [11,12,13]. Only the data that passed the first two quality check tests were used in the study [14,15,16].

After quality checks, the minute values were averaged to 15 minutes and then 4 slots of 15 minute averages were averaged to get hourly mean using the methodology used in our previous study [17]. Hourly mean values were then averaged to get daily mean values and monthly mean values were calculated from daily mean values and from monthly mean values annual average values were calculated.

Daily CM SAF Surface incoming shortwave radiation (SIS) data from Meteosat Second Generation (MSG) with a spatial resolution of 0.05° x 0.05°, covering a period from 1983 to 2019 were also used in the study [18]. Daily insolation data from (NASA), (SSE) with a spatial resolution of 1° x 1° [19], covering a period from 2013 to 2019 were also used in the study.

CMSAF SIS and NASA SSE daily mean data sets were validated using mean daily GHI per month from each station (i.e. measured data) and then the overall aggregated means were calculated from the monthly MAD for each station. Monthly averages per year were calculated from quality checked observation data, aggregated monthly means and standard deviations were calculated from monthly means. Aggregated seasonal and annual means were also calculated from monthly means. The coefficient of determination (r^2), a measure used in statistical analysis to assesses how well a model explains and predicts future outcomes was used in the analyses of the different data sets. This measure gives an indication of the level of the variability in the data set and is used as a guideline to measure the accuracy of a model or specific data set. Another statistical metric used was the mean absolute deviation, which is the average distance between data points and the mean and gives an idea of the variability in a data set (i.e. high variability indicates the data are spread out while low variability indicates that the data are clustered together).

3. Results and Discussions

3.1 BSRN QC results

The BSRN QC approach [11,12,13] was applied to check the quality of minute GHI data and suspected values were discarded before conducting any analysis. The results were as shown in Table 2 and these show that the overall percentage was good indicating that the data were of good quality with an average of 98.25 %. All 13 stations had more that 95 % and less than 5 % erroneous data, missing data (i.e. data coded 5) and data that failed comparison tests (i.e. when GHI parameters were compared to other radiation parameters and coded 16 and 32) dominated the percentage of bad data with 1.36 %, 1.07 % and 3.76 %.

Station/Code	0	5	8	10	16	32	40	0+16+32
Prieska	96.12	3.59	0.00	0.00	0.02	0.26	0.00	96.40
Upington	96.74	1.64	0.04	0.01	0.07	1.49	0.00	98.30
De Aar	97.66	1.38	0.00	0.00	0.60	0.36	0.00	98.61
Irene	97.07	0.03	0.07	0.88	1.23	0.41	0.10	98.71
Nelspruit	92.22	0.67	0.10	0.71	0.23	6.00	0.05	98.45
Mahikeng	92.87	0.59	0.07	0.84	1.56	3.93	0.13	98.36
Mthatha	94.13	0.55	0.14	0.72	0.44	3.91	0.05	98.48
Bethlehem	91.08	4.36	0.01	0.00	0.27	4.26	0.02	95.61
Cape Point	79.61	1.61	0.37	0.00	1.82	16.55	0.03	97.98
George	99.21	0.00	0.00	0.00	0.23	0.54	0.02	99.98
Durban	94.26	0.01	0.00	0.00	1.14	4.58	0.00	99.97
Polokwane	92.54	0.98	0.03	0.12	0.96	5.27	0.08	98.77
Thohoyandou	91.05	2.27	0.00	0.00	5.31	1.26	0.00	97.62
Overall	93.43	1.36	0.06	0.25	1.07	3.76	0.04	98.25

Table 2: Summarises the BSRN QC results as percentages of the data associated with a code per station

3.2 Validation results

Daily GHI values were compared to their corresponding values from CMSAF SIS and NASA SSE and the results are shown in Table 3. As shown in Table 3, CMSAF data showed a very good relationship when compared with the observation data with an overall MAD of 11.81 W/m^2 and r^2 of 0.943. NASA SSE showed an overall MAD of 19.59 W/m^2 and r^2 of 0.870. All the stations met the optimal accuracy target of 15 W/m^2 [20] when compared to CMSAF SIS data set.

Station	OBS	CMSAF	NASA	CMSAF(MAD)	NASA(MAD)	CMSAF(R2)	NASA(R2)
Upington	265.64	259.08	256.53	12.62	15.14	0.948	0.922
Prieska	253.80	253.41	250.96	9.96	13.26	0.970	0.941
De Aar	253.00	249.90	246.21	11.49	16.75	0.958	0.915
Irene	231.28	237.13	234.59	12.38	18.20	0.904	0.850
Nelspruit	205.05	212.62	210.69	11.90	19.66	0.945	0.867
Mahikeng	248.24	248.22	239.81	13.28	16.54	0.917	0.880
Mthatha	192.01	196.99	198.77	10.60	18.20	0.963	0.899
Bethlehem	235.00	235.84	227.38	9.97	18.51	0.955	0.886
Cape Point	218.00	220.43	236.27	12.06	25.37	0.936	0.781
George	195.26	200.61	208.32	10.58	30.18	0.971	0.772
Durban	186.08	191.48	192.78	10.40	19.54	0.950	0.873
Polokwane	232.23	235.15	227.67	11.09	20.00	0.931	0.836
Thohoyandou	207.93	221.93	218.37	16.92	23.26	0.915	0.847
OVERALL	224.89	227.91	228.79	11.81	19.59	0.943	0.870

Table 3: Summaries the validation results between SAWS GHI observations, CMSAF SIS and NASA SSE.

Using CMSAF SIS data sets, climatological trends can also be determined. In this paper, a case study of Polokwane GHI data sets from 1983 to 2018 were analysed. The results were as shown in Figure 2 and reveal that the GHI quantities fluctuate, and the trend line shows general decrease over the time. From Figure 2, the long term average from 1983 to 2018 was 231.6 W/m^2 and this value falls within the annual average that was calculated using observation data 232.23 W/m^2 +SD (i.e. 232.23 ± 9.63 W/m^2).

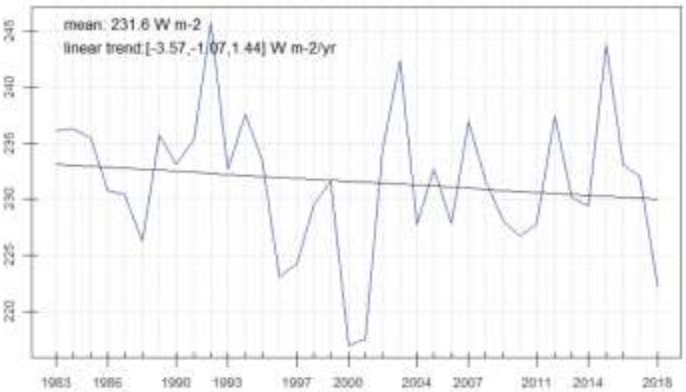

Figure 2: Polokwane GHI annual climatology and trends from 1983 to 2018 using CMSAF SIS satellite data.

The CMSAF SIS gridded data set can also be used to get a full map of the country showing daily mean, monthly mean, seasonal mean and annual mean values represented by different colours. In this paper, the mean monthly GHI values for January 2017 for South Africa was represented as shown in Figure 3. In January 2017, Thohoyandou received lowest amount of SIS ranging from 235-245 W/m^2 and Upington received the highest amount of SIS ranging from 340-350 W/m^2. These values were in agreement with the long term monthly average observation for January with Upington having the highest of 343.99±SD and Thohoyandou 243.72±SD.

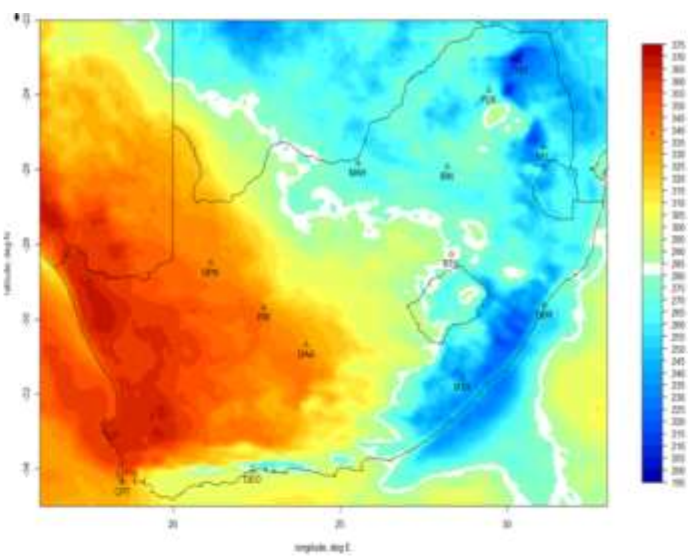

Figure 3: CMSAF SIS gridded data set used to plot January 2017 monthly mean for a whole South Africa.

Aggregated monthly means and their standard deviations (SD) were calculated using monthly means calculated from minute quality checked GHI values and the results are as shown in Table 4 and Table 5. The highest GHI value of 370.18 W/m^2 was recorded in Upington in December while Cape Point recorded the lowest GHI of 98.51 W/m^2 in June. Of all the stations, Upington had the highest annual GHI of 265.63 W/m^2 while Durban had the lowest annual value of 186 W/m^2. The annual SD ranged from 8.72 W/m^2 to 15.12 W/m^2. Cape Point had the lowest annual variability while Irene had the highest annual variability. It was observed that that the variability was generally higher in summer when the values of GHI were high and lower in winter when the GHI values were low.

Station	Variable	Jan	Feb	Mar	Apr	May	Jun
PRI	Mean	330.89	342.45	268.61	211.46	170.09	145.88
	SD	12.73	13.46	8.67	4.90	11.02	11.40
UPN	Mean	343.99	319.04	282.39	219.03	182.30	160.24
	SD	21.92	18.42	4.94	5.24	3.40	9.78
DAA	Mean	331.60	313.81	271.24	200.95	163.28	144.26
	SD	14.34	17.38	8.49	9.17	6.50	10.76
IRN	Mean	278.01	251.27	238.86	195.39	174.10	166.15
	SD	18.31	24.33	19.75	15.78	11.57	6.38
NEL	Mean	252.74	222.79	225.20	184.24	170.63	160.09
	SD	13.38	10.23	5.05	22.24	19.23	6.67
MAH	Mean	296.66	253.00	260.73	204.79	184.53	172.49
	SD	28.75	24.44	11.09	10.85	1.86	7.27
MTH	Mean	250.65	227.11	191.90	166.71	140.73	129.22
	SD	16.58	20.59	27.41	7.84	9.01	7.43
BTH	Mean	303.50	279.10	222.94	189.07	169.39	156.46
	SD	24.81	18.19	22.17	14.44	11.68	6.78
CPT	Mean	313.72	301.64	234.13	180.52	123.59	98.51
	SD	10.75	9.17	7.47	8.16	11.98	2.24
GEO	Mean	271.09	249.70	200.39	159.82	121.95	101.80
	SD	7.69	9.85	10.23	6.29	8.29	0.85
DBN	Mean	256.54	234.81	201.53	165.18	140.59	128.03
	SD	24.38	23.42	11.51	7.98	3.78	5.26
PLK	Mean	281.77	228.62	245.84	194.80	184.65	173.36
	SD	20.30	3.13	2.01	4.15	8.37	4.83
THO	Mean	243.72	217.37	218.84	178.15	172.25	155.11
	SD	9.91	18.43	14.50	5.67	13.25	7.55

Table 4: Aggregated monthly mean (Mean) and SD from January to June.

Jul	Aug	Sep	Oct	Nov	Dec	Annual
157.79	180.65	248.09	311.85	336.79	341.03	253.80
10.93	4.24	10.31	1.61	7.16	17.50	9.49
169.53	209.71	253.27	319.93	358.05	370.18	265.63
6.31	14.80	6.27	8.06	12.93	17.04	10.76
155.06	193.97	243.96	305.04	345.56	367.27	253.00
7.29	12.23	9.79	5.40	18.10	10.45	10.83
175.20	212.23	244.62	277.30	281.15	281.12	231.28
6.74	14.34	12.86	15.95	17.47	18.00	15.12
160.99	190.46	206.09	218.85	224.22	244.28	205.05
3.33	16.23	17.04	15.92	19.97	12.62	14.31
181.62	214.47	258.26	297.40	322.55	320.59	248.24
6.01	10.09	4.48	8.71	7.41	7.64	10.72
137.33	161.13	193.30	224.75	241.35	251.20	192.95
14.36	6.94	16.02	2.45	8.12	20.89	13.14
161.75	200.67	240.43	282.99	313.56	300.05	235.00
9.38	13.84	16.54	11.59	0.00	12.79	13.52
112.50	150.65	191.72	259.69	314.08	335.25	218.00
4.03	19.03	10.35	11.10	9.80	13.60	8.72
112.54	143.22	184.67	234.77	266.34	296.79	195.26
12.80	10.18	7.76	10.43	14.23	14.69	9.44
127.95	157.33	166.96	201.57	218.59	233.94	186.08
7.68	13.63	12.10	16.57	25.61	11.96	13.66
179.90	208.49	242.61	278.77	285.58	282.79	232.23
3.94	7.20	14.86	15.19	12.47	19.10	9.63
161.29	204.99	207.25	229.89	240.77	285.60	207.93
11.03	19.50	1.92	7.60	25.29	19.97	12.88

Table 5: Aggregated monthly mean and standard deviations from July to December.

Aggregated seasonal averages and annual averages were also calculated with their corresponding CMSAF SIS values and the results are shown in Figures 4 -7. From the results, stations in arid, cold and temperature interior climatological regions had consistently higher GHI values with annual values of more than 230 W/m^2 while stations in hot interior, subtropical coastal and temperature coastal climatological regions had consistently lower GHI values with annual values of less than 220 W/m^2.

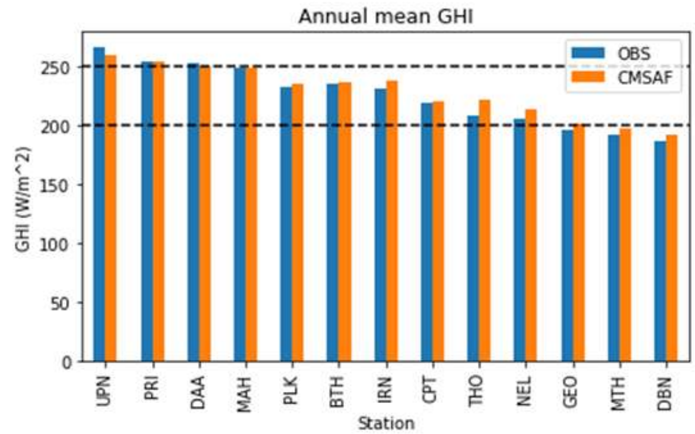

Figure 3: Aggregated annual mean GHI for all SAWS radiometric stations.

The annual mean GHI ranged from slighted greater than 250 W/m^2 to slightly less than 200 W/m^2, most of the stations had GHI values between 200 W/m^2 and 250 W/m^2.

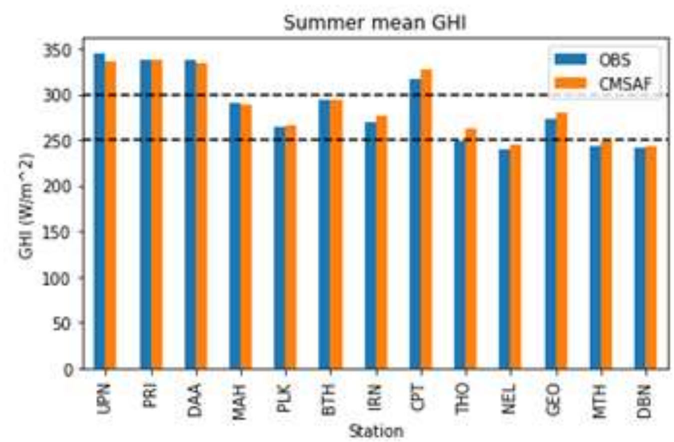

Figure 4: Aggregated summer (December, January and February) mean GHI for all SAWS radiometric stations.

Upington, De Aar, Prieska and Cape Point received more than 300 W/m^2 GHI while Nelspruit, Durban and Mthatha stations receives less than 250 W/m^2 in summer.

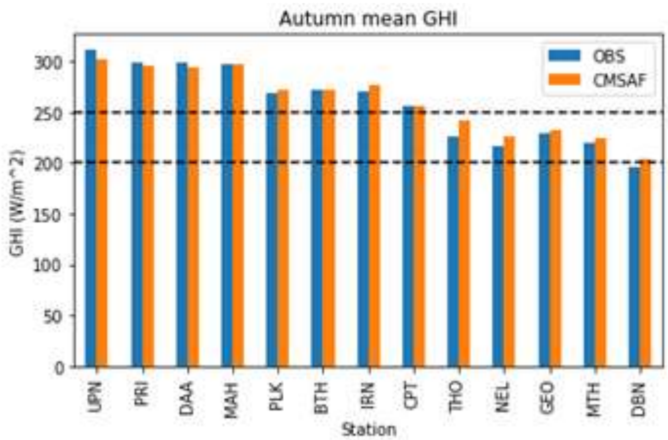

Figure 5: Aggregated autumn (March, April and May) mean GHI for all SAWS radiometric stations.

In autumn all the stations except Durban received more than 200 W/m^2.

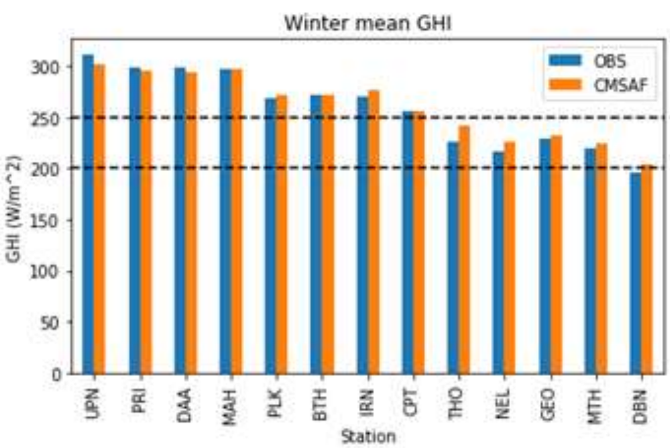

Figure 6: Aggregated winter (June, July and August) mean GHI for all SAWS radiometric stations.

In winter all the stations except Durban received more than 200 W/m^2.

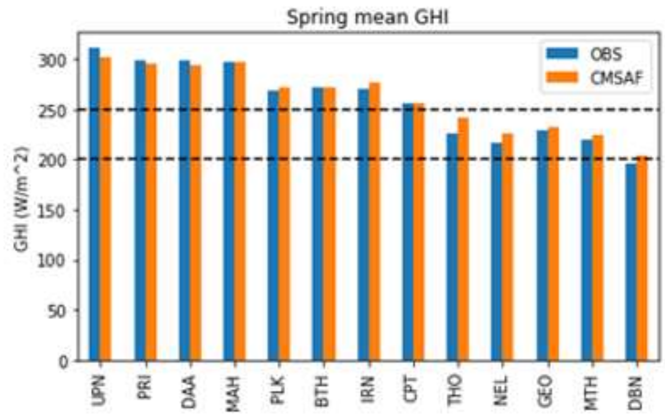

Figure 7: Aggregated spring (September, October, November) mean GHI for all SAWS radiometric stations.

In spring all the stations except Durban received more than 200 W/m^2. GHI amounts decreased from Northwest of the country to Southeast, with inland stations having slightly higher GHI values than coastal stations this can be because of lower elevation, high humidity and cloudiness conditions on the coastal sites.

5. Conclusion

The GHI data quality recorded at SAWS was found to be of good quality with less than 5 % of data being erroneous based on the BSRN quality check test. This indicates that the data are reliable for use in solar resource assessment. CMSAF SIS data showed a very good relationship with observed data compared to NASA SSE data and it also met the optimal accuracy target of 15 W/m^2. The validation process confirmed that these data can be used with confidence for different renewable energy applications. The mean monthly, seasonal and annual values can be useful in providing solar radiation information that can be used to make decisions regarding the location and selection of solar energy technologies. The radiation amounts were higher in summer than in winter as expected for locations in the Southern hemisphere. According to [21] detection of climatological variation requires at least decadal monitoring of solar radiation and testing the accuracy of understanding of the climate system and the anthropogenic process requires half of a century of observations; to achieve this SAWS continue to focus on minimizing data loss and regular calibration of the radiometric network for long term measurement of reliable, high quality solar radiation data sets.

Acknowledgements

We want to acknowledge Department of Science and Technology (DST) who helped with the funding of the installation of the SAWS SOLYS radiometric network. SAWS staff from regional offices for the continuous efforts in helping with station inspection, cleaning and maintenance and the National Research Foundation (NRF) of South Africa. Dr. Amelie Driemel, Director of the World Radiation Monitoring Center who helped us with some answers related to the BSRN toolbox software operation and Mr. Louis van Hemert from SAWS who helped with the FORTRAN code to convert data from station-to-archive format.

References

[1] M. D. Lysko, (2006). Measurements and Models of Solar Irradiance, Doctoral Thesis, Norwegian University of Science and Technology, Faculty of Natural Sciences and Technology, Department of Physics, Trondheim.

[2] A.D. Pai, J.F. Escobedo, D. Martins, E.T. Teramoto, (2014). Analysis of hourly global, direct and diffuse solar radiations attenuation as a function of optical air mass, Energy Procedia, Vol. 57, 2014, pp. 1060-1069.

[3] A. Driemel, et al, (2018). Baseline Surface Radiation Network (BSRN): Structure and data description (1992-2017), Journal Earth Syst. Sci. Data.

[4] E. Zell, S. Gasim, S, Wilcox, et al, (2015). Assessment of solar radiation resources in Saudi Arabia. Solar Energy 2015; 119:422–38.

[5]K.R. Kunene, (2011). Broadband solar radiometric measurements in the greater Durban area. MscEng Thesis, University of KwaZulu-Natal.

[6] H.P. Garg, S.N. Garg, (1993). Measurement of solar radiation _1. Radiation Instruments. Renewable Energy, 3(4/5), 321-333.

[7] A. Luis, P. Jesus, F. Díaz, J.M. Vindel, (2018). Solar Radiation Gridded Satellite data comparison in Gran Canaria Island. Renewable Energy and Power Quality Journal.

[8]S. Marko, et al, (2014). Quality Check Procedures and Statistics for the Indian SRRA Solar Radiation Measurement Network. Energy Procedia.

[9]B.Y. Kim, K.T. Lee, I.L. Zo, H. Sang, H.S. Jung Rim, H. Se, J.P. Jang, (2018). Calibration of the Pyranometer Sensitivity Using the Integrating Sphere. Asia-Pacific Journal of Atmospheric Sciences. 10.1007/s13143-018-0085-0.

[10] J.D. Wood, T.J. Griffis, J.M., Baker, (2015). Detecting drift bias and exposure errors in solar and photosynthetically active radiation data. Netherlands: N. p., 2015.

[11] C.N. Long, E.G. Dutton, (2002). BSRN Global Network Recommended QC Tests, V2.0. BSRN Technical Report (2002). Available online: http://ezksun3.ethz.ch/bsrn/admin/dokus/qualitycheck.pdf (accessed on 17 July 2019).

[12] H. Schmithüsen, (2012). Quality Checks offered by the BSRN Toolbox. 12th Baseline Surface Radiation Network (BSRN) Scientific Review and Workshop, Alfred Wegener Institute, Potsdam, Germany, 1 August 2012 - 3 August 2012, hdl:10013/epic. 44437.d001. Available online https://epic.awi.de/id/eprint/36656/1/12th_BSRN_Meeting_Schmithuesen.pdf (accessed 15 July 2019).

[13] A. Roesch, M. Wild, A. Ohmura, E.G. Dutton, C. N, Long, T Zhang, (2011). Assessment of BSRN radiation records for the computation of monthly means. Atmos. Meas. Tech. 2011, 4, 339–354.

[14] C. Thomas, E. Wey, P. Blanc, L. Wald, (2016). Validation of three satellite-derived databases of surface solar radiation using measurements performed at 42 stations in Brazil Adv. Sci. Res., 13 (2016), pp. 81-86.

15] R. Urraca, A.M. Gracia-Amillo, T.Huld, F.J.Martinez-de-Pisona, J. Trentmanne, A.V.Lindforsf, A. Riihelaf, A.Sanz-Garcia, (2017). Quality control of global solar radiation data with satellite-based products. Solar Energy 2017, 158, 49–62.

[16] A.Riihela, V. Kallio, S.Devraj, A.Sharma, A.V.Lindfors, (2018). Validation of the SARAH-E Satellite-Based Surface Solar Radiation Estimates over India. Remote Sens. 2018, 10, 392.

[17] B. Mabasa, J. Botai, L. Ntsangwane, (2018): Update on the Re-Establishment of the South African Weather Services (SAWS) Radiometric Network in All Six Climatological Regions and the Quality of the Data, SASEC 2018, Durban.

[18] CMSAF Available online: https://www.cmsaf.eu/EN/Products/AvailableProducts/OperationalProducts/graphics/SISmm20090701000030307001080 1CA.html?nn=1890166 (accessed on 17 July 2019).

[19] NASA Available online: https://eosweb.larc.nasa.gov/sse/ (accessed on 14 June 2019).

[20] R. Posselt, R.W. Mueller, R. Stockli, J. Trentmann, Remote Sensing of Solar Surface Radiation for Climate Monitoring -The CM-SAF Retrieval in InternationalComparison, Remote Sensing of Environment 118 (2012) 186–198.

[21] A. Ohmura, et al, (1998). Baseline surface radiation network (BSRN/WCRP): New precision radiometry for climate research, B. Am.Meteorol. Soc., 79, 2115–2136