Acquisition and Study of Global Solar Radiation in Maroua-Cameroon

Fotsing Talla Cyrille*,**‡, Njomo Donatien*, Cornet Céline***, Dubuisson Philippe***, Nsouandele Jean Luc*

*Environmental Energy Technologies Laboratory (EETL), University of Yaounde 1, Cameroon

**Physics Department, Higher Teachers' Training College, University of Maroua, Cameroon

***Atmospheric-Optics Laboratory (LOA), Lille 1 University - Sciences and Technologies, 59655 Villeneuve d'Ascq Cedex-France

(tallacyrille@yahoo.fr, dnjomo@usa.net, celine.cornet@univ-lille1.fr, philippe.dubuisson@univ-lille1.fr, jlnsouandele@yahoo.fr)

‡ Corresponding Author: Fotsing Talla Cyrille, 78 Maroua-Cameroon, Tel: +237 677 341 172, tallacyrille@yahoo.fr

Received: 27.05.2015 Accepted:07.07.2015

Abstract- Solar radiation in Maroua-Cameroon was measured during different time period with various instruments. It is essential to know the validity and continuity of these data by comparison. Concerning the measurements, Cameroon witnessed an only solar radiation measurement campaign that leads to the year 1984 database. At the Maroua-Salak weather station, sunshine duration record stopped since 2005 because of logistic difficulties. The Vantage Pro2 Plus autonomous weather station is now installed since 2014 to measure global solar radiation. Besides, a method is established in order to deduce sunshine durations from irradiations measurements and daily solar radiation is computed with the Angstrom formula. This new procedure gives clear improvements both in data facility acquisition and record reliability. The results show that Maroua actual solar potential increased to 3490.86 hours or 1933.07 kW.h.m^{-2} per year. Empiric relations previously established there overestimate solar radiation and consequently should be updated. There are many discrepancies with old records of Maroua-Salak station in term of annual variation and scale values. In case of non-availability of recent in-situ measurements, RETScreen International software predictions are recommended. The region needs without doubt new meteorological equipments and should exploit atmospheric data from satellite. In addition, long term measurements with smallest acquisition data time could improve knowledge of actual sunshine behavior in Maroua and its impact on climate and human activities. Analysis of this work provides to the Ministry of Mining Water and Energies and the National Meteorological Service a way of restarting reliable and sustainable solar data acquisition and exploitation.

Keywords- Global solar radiation; Sunshine duration; Solar potential; Autonomous weather station; Maroua.

1. Introduction

Cameroon witnessed a large demographic expansion these last years, and its growing energetic need is not consequently satisfied [1]. This is the situation faced by Maroua town (10°35′50″N, 14°18′57″E) in the Far-North region of the country. This town is located in the Diamare plain characterized by a Sudan-Saharan climate. It receives a high rate of solar radiation which constitutes an important source of energy for the development of activities such as farming, architecture, tourism, solar energy applications [2, 3]. Being a region of cereals and recently an emerging truck farming region, the food needs in Maroua increase while farmers are facing seasonal shift difficulties [4]. The mastering of these activities requires a good updated knowledge of site sunshine [5, 6, and 7]. Many works were based on these data and some helped to show that the town of Maroua has a high rate of sunshine [3, 8, 9, and 10]. Difficulties due to outdated equipments and lack of permanent follow-up have leaded to an interruption on measurement in many regional weather stations as well as in Maroua-Salak. This station has a Campbell-Stockes recorder (CSR) from which sunshine duration (SD) measurements were taken up until 2005. Nowadays, defective equipments as well as reading and manual report errors cause difficulties to firms exploiting this precious information. The previous observations bring up interrogations on the accuracy of old sunshine databases, how to facilitate their acquisition and which one offers the best information. Therefore, an autonomous weather station is currently being experimented to measure the global solar radiation in Maroua and to deduce SD during the year 2014.

In section 2, four different sunshine datasets available in Maroua are presented. The methodology to deduce SD from solar radiation data and how to calculate the monthly mean daily irradiations using Njomo coefficients of the Angstrom formula [8], are shown in section 3. In section 4, the different values of SD obtained and their corresponding solar radiation values are analyzed and compared.

2. Maroua Sunshine Data

2.1. Maroua-Salak sunshine duration records between 1983 and 2005

In meteorology, "insolation" stands for solar irradiation value above the threshold of 120 $W.m^{-2}$ corresponding to a light intensity sufficient to produce perfect black shadows. The SD during a period rather refers to the sum of sub-periods for which there is insolation. At this threshold intensity, the CSR sunshine card burns. Measurement of the total burn length gives the SD of the period. The CSR of Maroua-Salak station (10°28'N, 14°16'E) was installed at an altitude of 423 m. It is no more functional today, but has helped to record SD during twenty-three years, running from 1983 to 2005, as reported in Maroua-Salak climatologic reports. For this work, only years with at least six months of recording have been exploited for the calculation.

2.2. The solar radiation measurement campaign database of 1984

The Laboratory for Research on Energies (LRE) of the Research Institute of Geological and Mining Research (IGMR) in Cameroon has carried-out the unique solar radiation measurement campaign over the ten regions of Cameroon from 1982 to 1987. Hourly global and diffuse solar radiations were measured with Eppley PSP pyranometers associated to LICOR integrators. Data was recorded and averaged every hour from 6 am to 6 pm mean solar time. Only records of 1984 were consistent and were published in [11, 12]. For Maroua, we found 253 full day records over the 366 days of this year. April and November have no data recorded.

2.3. Solar radiation measurement with autonomous weather station Vantage Pro2 Plus in 2014

The autonomous wireless weather station Vantage Pro2 Plus (VANTAGE) [13] has been installed in Maroua (10°36,840'N, 14°21,683'E) in 2014. The equipment is in an area free from shadows and obstacles and at an altitude of 398 m including its 5 m height for supporting stand. VANTAGE includes two components: the Integrated Sensor Suite (ISS) which houses and manages the external sensor array, and the console which provides the user interface, data display, and calculations. ISS is solar powered with a battery backup. It includes Davis' solar radiation sensor [14] with a spectral range from 300 to 1100 nanometers. Measurement resolution is 1 $W.m^{-2}$ on a scale of 0 to 1800 $W.m^{-2}$, with a precision of ±5% of full scale (Reference: Eppley PSP at 1000 $W.m^{-2}$). The software Weatherlink interfaces the station with a computer in order to log or to download weather data, especially global solar radiation. VANTAGE registered global solar radiation in 2014 everyday 24h/24 with three successive temporal resolutions: 30 minutes from January to August, 5 minutes for September and 1 minute from October to December respectively.

2.4. The RETScreen International software data

RETScreen is a Clean Energy Management Software system for energy efficiency, renewable energy and cogeneration project feasibility analysis as well as ongoing energy performance analysis [15]. It gives directly area monthly mean daily solar radiation ($H_{\_Rets}$) and its annual average, but does not provide SD. Local engineers in Renewable Energies learn how to use it in their training at the Sahelian Institute of The University of Maroua.

3. Methodology

3.1. Deduction of sunshine duration and daily global solar radiation from *global solar radiation measurement*

A new determination method of daily SD has been established. It consists in counting irradiation measurements reaching the value of 120 $W.m^{-2}$, assuming that each one is constant during the measurement interval. Considering M, the measurement number of periods in the day, T_i, the i^{th} period duration, SI_i, the i^{th} solar irradiation measured and δ_D the Dirac delta function equal to 1 if $SI_i \geq 120W.m^{-2}$ and 0 otherwise. The daily SD is obtained by:

$$\text{Daily SD} = \sum_{i=1 \text{ to } M} T_i \delta_D(SI_i \geq 120W.m^{-2}) \quad (1)$$

We distinguish three types of SD: the monthly averages of daily SD calculated from data obtained from 1983 to 2005 in Maroua-Salak station (SD_{Mes}), those deduced from LRE campaign (SD_{LRE}) and from VANTAGE measurements (SD_{Vant}). The daily global solar radiation His calculated with equation (2):

$$H = \sum_{i=1 \text{ to } M} SI_i \delta_D(SI_i \geq 120W.m^{-2}) \quad (2)$$

3.2. Estimation of solar radiation from Angstrom formula

From the studies of solar radiation in Cameroon, only that of Njomo [8] proposes for the Far-North region coefficients of Angstrom formula permitting to determinate daily global solar radiation (H):

$$H = H_0 (0.24 + 0.56(n/N)) \quad (3)$$

Where n and N are respectively measured and theoretical daily SD:

$$N = (2/15)\cos^{-1}(-\tan\varphi\tan\delta) \quad (4)$$

H_0, the extra-atmospheric solar radiation is determined by equation (5):

$$H_0 = (24I_{cs}/\pi)\ (1 + 0.033\cos(360x/365))* (\cos\varphi\cos\delta\cos\omega_s + (2\pi\omega_s/360)\sin\varphi\sin\delta) \quad (5)$$

Where I_{cs} = 1367 $W.m^{-2}$ represents the solar constant, x is the number order of the day of this year and φ is the latitude of the area. The solar declination angle δ and the sunset angle ω_s are given by:

$$\delta = 23.45°\sin((360/365)(284+x)) \quad (6)$$

$$\omega_s = \cos^{-1}(-\tan\varphi\tan\delta) \quad (7)$$

H_{d_Vant} and H_{d_Mes} are monthly daily solar radiation means computed from equation (3) by replacing n respectively by SD_{Vant} and SD_{Mes}. They are calculated for mean month days proposed by Klein [16] : x∈[17, 45, 73, 119, 136, 163, 198, 223, 259, 289, 318, 344].

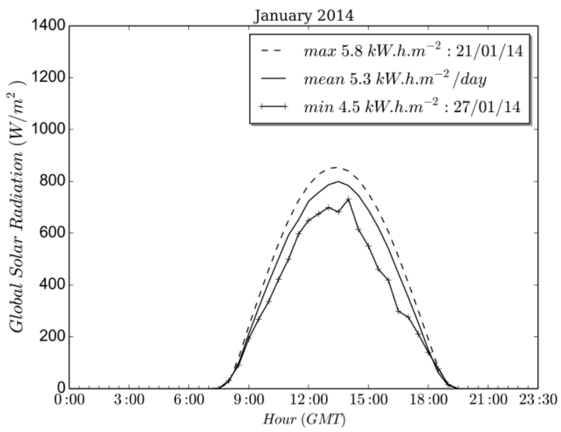
3.3. Statistical calculation

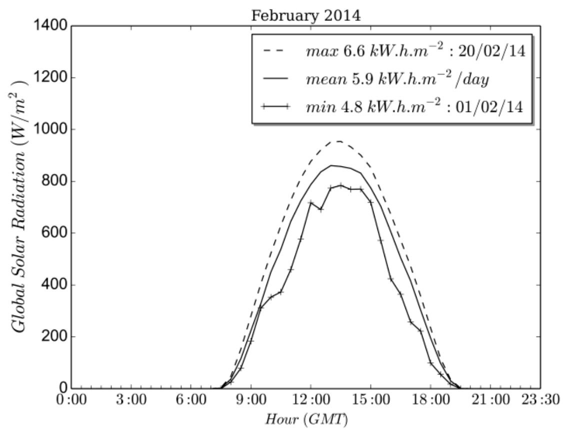
Data transmission errors, failure periods and maintenance of equipments or missing records produce erroneous values. They are therefore excluded in calculation as well as days concerned. The averages are calculated with the fully recorded days. For sum calculations, the gaps produced by missing data are filled by average values previously calculated while excluding them. Only irradiations over 120 $W.m^{-2}$ are considered for the evaluation of solar potential power.

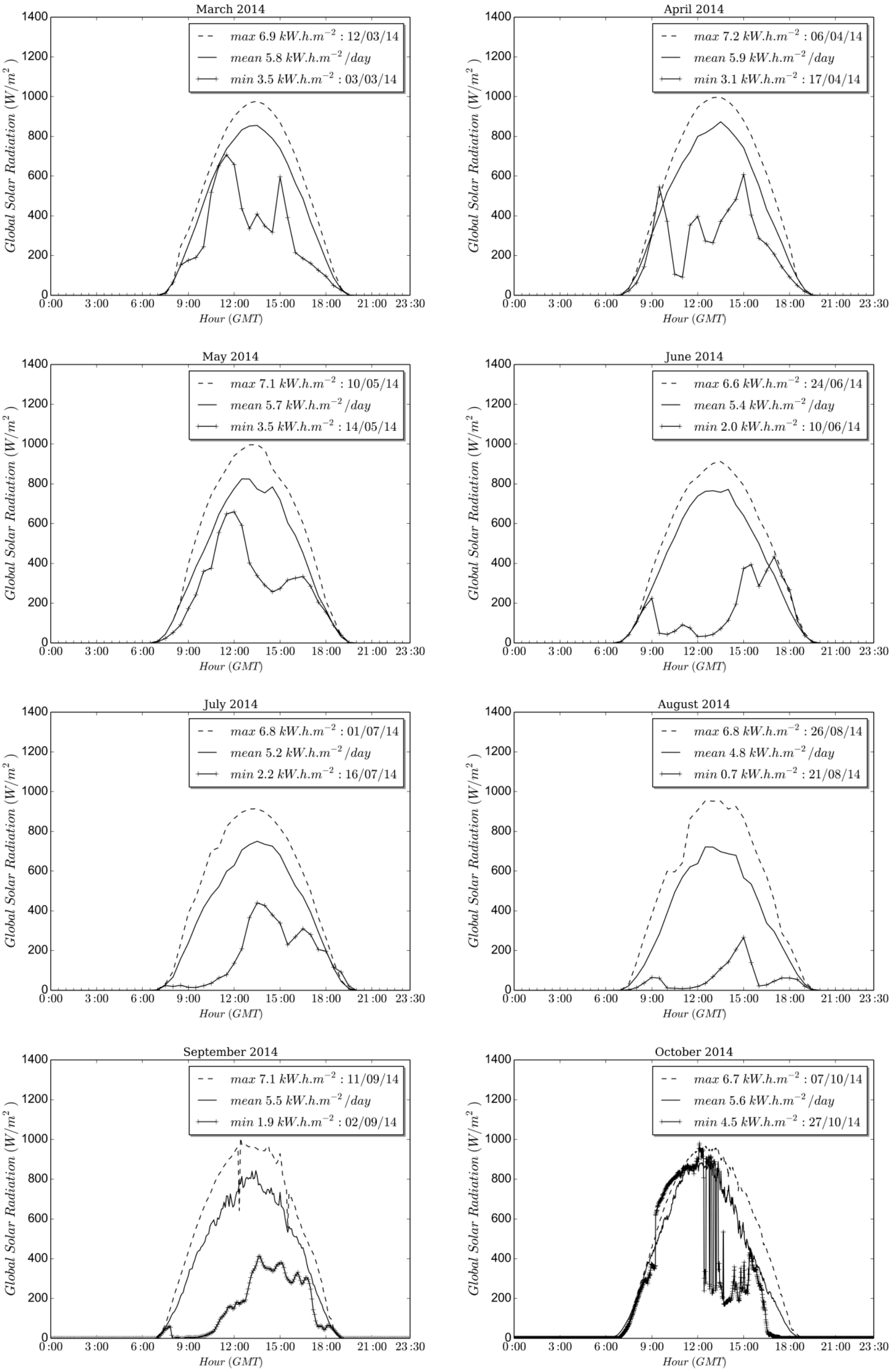
4. Results and Discussion

4.1. Maroua solar radiation measured in 2014 and deduced sunshine duration

For each month of 2014, Fig. 1 shows hourly variations of monthly mean global solar irradiation as well as the monthly minimum and maximum daily radiation. A symmetric daily monthly average curve means that the atmosphere has a relative constant cloudiness during the days of that month. These figures show that throughout the year, in average, the atmosphere is almost constantly a little clouded and turbidity is fair. Exceptions occur in May, June, August and September during which the two half periods of the days are not equally illuminated. This corresponds to the rainy season with clouds or aerosols decreasing the sun illumination. From January to February, the three curves are close and mean curves present an apparent vertical symmetry. This means that atmosphere turbidity is small. Some permanent aerosols should be in the atmosphere, but nothing could be concluded about cloudiness because in 30 minutes many clouds can cross over the area. From March to September, there is a clear difference between the minimal and maximal. The average curve is closer to the maximal one showing that most of the days of these months should be clear. As we feared to lose cloudiness details because of the 30 minutes data acquisition period, it has been reduced in September to 5 minutes and to 1 minute the remaining months. From October to December, the three curves start to get closer. It is mostly due to radiation attenuation by aerosols rather than clouds. In general, the precision of the observable details on the curves increases when the temporal resolution of the measures decreases. For the three last months, where the data are acquired every minute, it is possible to detect tiny variations of the sky cloudiness.






March 2014
max 6.9 kW.h.m^-2 : 12/03/14
mean 5.8 kW.h.m^-2 /day
min 3.5 kW.h.m^-2 : 03/03/14
April 2014
max 7.2 kW.h.m^-2 : 06/04/14
mean 5.9 kW.h.m^-2 /day
min 3.1 kW.h.m^-2 : 17/04/14
May 2014
max 7.1 kW.h.m^-2 : 10/05/14
mean 5.7 kW.h.m^-2 /day
min 3.5 kW.h.m^-2 : 14/05/14
June 2014
max 6.6 kW.h.m^-2 : 24/06/14
mean 5.4 kW.h.m^-2 /day
min 2.0 kW.h.m^-2 : 10/06/14
July 2014
max 6.8 kW.h.m^-2 : 01/07/14
mean 5.2 kW.h.m^-2 /day
min 2.2 kW.h.m^-2 : 16/07/14
August 2014
max 6.8 kW.h.m^-2 : 26/08/14
mean 4.8 kW.h.m^-2 /day
min 0.7 kW.h.m^-2 : 21/08/14
September 2014
max 7.1 kW.h.m^-2 : 11/09/14
mean 5.5 kW.h.m^-2 /day
min 1.9 kW.h.m^-2 : 02/09/14
October 2014
max 6.7 kW.h.m^-2 : 07/10/14
mean 5.6 kW.h.m^-2 /day
min 4.5 kW.h.m^-2 : 27/10/14
Global Solar Radiation (W/m^2)
Hour (GMT)

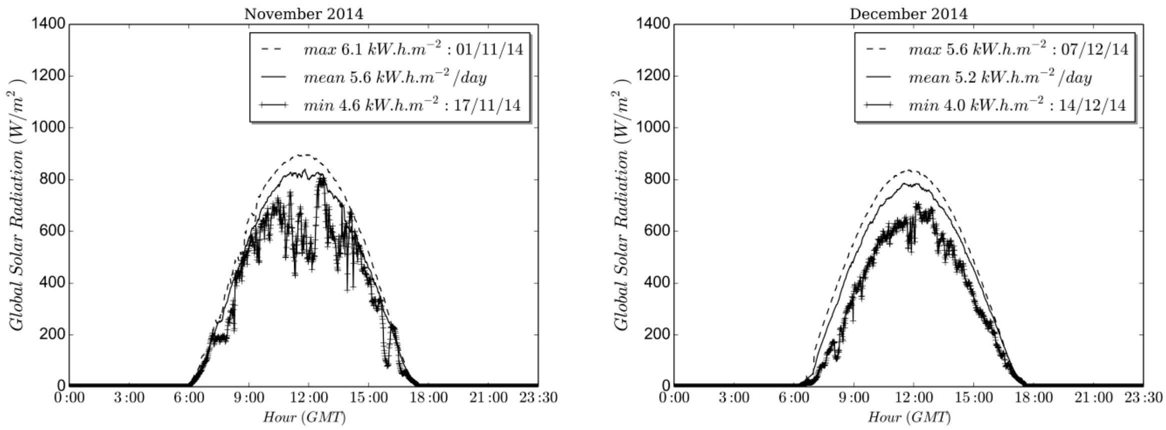


Fig. 1. Monthly mean of daily solar radiation from January to December 2014. The minimum and maximum of solar radiation are also indicated. The data acquisition is done every 30 minutes from January to August, every 5 minutes in September and every 1 minute from October to December.

From VANTAGE global solar irradiation registered in 2014 in Maroua, daily global solar radiation (h_{Vant}) have been computed using equation (2). In Fig.2, region I and region III show that from January to April and from October to December the curve is smooth, denoting a less clouded atmosphere. On the contrary, in region II the curve presents many minima from May to September. In that period, the sky is clouded most of the time and illumination is consequently reduced a bit. h_{Vant} annual mean is 5.48 kW.h.m^{-2} and standard deviation is 0.96 kW.h.m^{-2}. The annual minimum and maximum recorded are respectively 0.75 kW.h.m^{-2} and 7.19 kW.h.m^{-2}. SD_{Vant} was deduced by replacing SI_i by these daily values in equation (1).

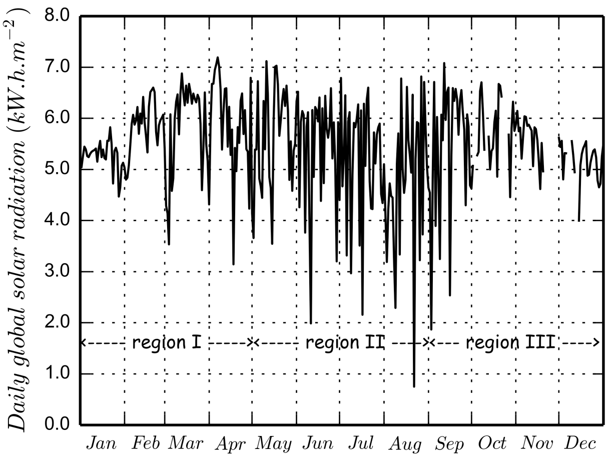


Fig. 2. Daily global solar radiation during 2014 in Maroua

Second column of Table 1. presents for each month the total, the minimum, the maximum, the maximum-minimum difference and the average SD. In the third column, it is the monthly averages and sums of solar radiation. April is the sunniest month with a daily average of 9.90 hours and 5.66 kW.h.m^{-2}. The month of August is the least sunny one with 8.81 hours and 4.53 kW.h.m^{-2} per day. Throughout the year, the town received 1933.07 kW.h.m^{-2} with an average of 5.30kW.h.m^{-2} per day, representing a total of 3490.86 h/year and a mean of 9.56 h/day of SD. Annual average of monthly SD's maximum-minimum differences is 3.39 hours. It divides the year into two periods showing the duality of the seasons found in this area:

- The period with differences below 3.39 hours occurs from January to April and October to December (region I and region III in Fig.2). This is a dry period characterized by cloudless sky giving less SD discrepancy.

- The period with differences beyond 3.39 hours occurs from May to September (region II in Fig2). This period is less dry and even humid when rains are around. The sky is generally clouded leading to large discrepancy of SD.

The exploitation of an autonomous weather station in the town of Maroua, comparatively to the CSR, removes difficulties and inconvenient due to manual SD recording. It provides more reliable and complete data and also allows the usage of different temporal measurement resolutions. This instrument can be brought everywhere and is a real access for studies throughout the entire country. For a better precision of SD and to have a brief characterization of the atmosphere turbidity, the usage of the shorter measurement interval is recommended.

Table 1. Sunshine duration and global solar radiation recorded in Maroua in 2014 with VANTAGE

	SD_{Vant} (hour)					h_{Vant} (kW.h.m^{-2})	
	total	max	min	max-min	mean	total	mean/day
January	294.50	10.00	9.00	1.00	9.50	157.29	5.07

February	273.00	10.50	9.00	1.50	9.75	158.55	5.66
March	304.50	10.50	8.50	2.00	9.82	173.75	5.60
April	297.00	11.00	8.50	2.50	9.90	169.98	5.66
May	303.00	11.00	6.00	5.00	9.77	168.19	5.42
June	284.50	11.00	5.00	6.00	9.48	153.96	5.13
July	297.00	10.50	6.50	4.00	9.58	154.76	4.99
August	273.00	11.00	2.00	9.00	8.81	140.54	4.53
September	287.50	10.50	5.92	4.58	9.58	159.53	5.32
October	290.65	10.20	7.40	2.80	9.38	173.57	5.60
November	291.62	10.13	8.93	1.20	9.72	165.23	5.51
December	294.60	9.85	8.70	1.15	9.50	157.74	5.09
Annual	3490.86	11.00	2.00	9.00	9.57	1933.07	5.30

4.2. Analysis of sunshine duration evolution from 1983 to 2005 and in 2014

Figure 3 shows the evolution of annual mean daily SD from 1983 to 2005 and in 2014 at the Maroua-Salak station. The variation of mean daily SD is not regular from 1983 to 1994. From 1996 to 1999, it increases linearly from 7.47 hours to 8.91 hours and decreases to 7.65 hours in 2002. Between 2002 and 2003 it increases again. In general, the daily SD oscillates between a minimum of 6.98 hours obtained in 1992 and a maximum of 8.91 hours in 1999. The standard deviation is 0.47 hours and general mean is evaluated to 8.02 hours. Because of the lack of data, the SD evolution between 2005 and 2013 is unknown. The SD variability is sometimes due to natural variability of the weather but the new value obtained in 2014 (09.57 hours/day) is greater than the previous one plus four times the standard deviation and it is the highest ever registered. As mentioned by Matuszko [17], automatic sensors can give greater values than the CSR, but this last evolution is very surprising and it is difficult to know if it is a real evolution or if it is just due to the change of measurement method.

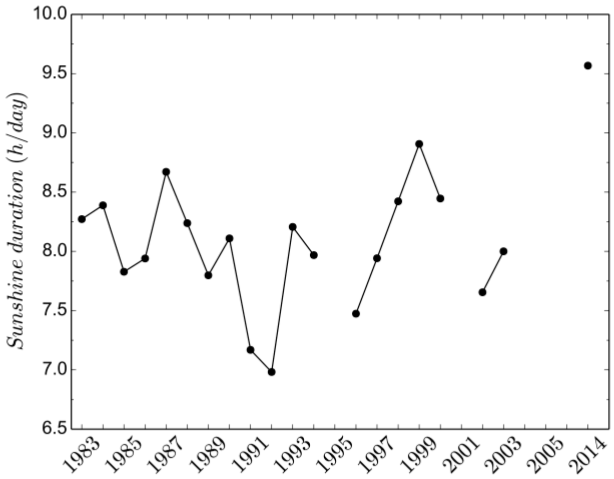


Fig. 3. Temporal evolution of annual mean daily sunshine duration in Maroua from 1983 to 2014

One way to answer to this interrogation is to plot the SD obtained by different ways: SD_{Mes}, SD_{LRE} and SD_{Vant} (Fig. 4).

Even if values were not acquired during the same year, we see that the SD_{Vant} and SD_{LRE} are very close excepted during the July-September variation. Their correlation coefficient is 0.544. LRE irradiation measurements were averaged on the one hour period in the final database. It may results in loss of details, which could explain some of the observed divergences.

For SD_{Mes} and SD_{Vant}, the coefficient of correlation is 0.546, but SD_{Mes} curve is far from the two previous ones. The annual monthly mean is 7.97 hours for SD_{Mes}, 9.65 hours for SD_{LRE} and 9.57 hours for SD_{Vant}. For the year 1984, SD_{Mes} mean was 8.39 hours; it is different from the LRE value for the same year. However, there is only few degrees difference between SD_{Mes} and SD_{Vant} measurement point coordinates. In addition, CSR sunshine cards, sensitive to the entire solar spectrum, should have given greater values than those obtained by the VANTAGE, whose spectral action varies between 300 and 1100 nanometers.

All these observed differences traduce the inadequacy of Maroua CSR which underestimate the SD. If this recorder has to be used again, a preliminary study with reference equipment as the LP SD18 SD recorder [18] should be done to investigate the error sources. To evaluate more accurately the concordance of the three SD datasets and fix the discrepancies, more measurements campaigns are necessary.

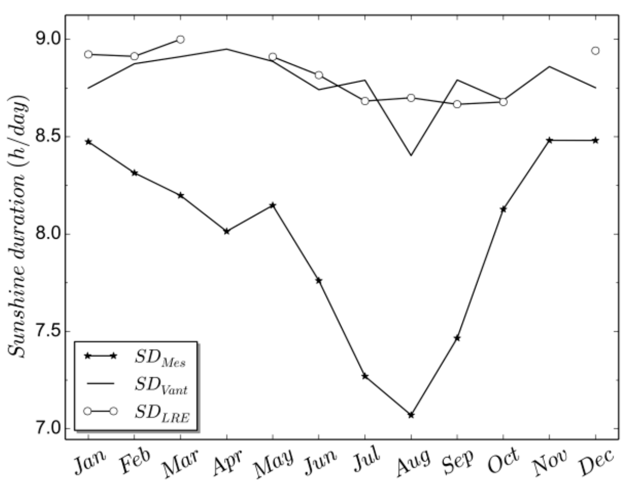


Fig. 4. Annual variation of monthly daily sunshine duration in Maroua from 1983 to 2005 for SD_{Mes}, 1984 for SD_{LRE} and in 2014 for SD_{Vant}

4.3. Analysis of global solar radiation evolution in Maroua from 1983 to 2005 and in 2014

h_{Vant} are used to compute VANTAGE monthly average daily solar radiation : H_{vant}. Annual deduced values of H_{d_Mes} and H_{d_Vant} are compared in Fig. 5 with measured ones H_{LRE} and H_{Vant}, along with RETScreen results $H_{\_Rets}$. Their linear regression equations are presented in Table 2.. r represents the correlation coefficient and s is the standard error of estimation. In this annual basis, H_{d_Mes} and $H_{\_Rets}$ are strongly correlated with H_{vant} (r=0.87) and fairly with the others. They also have greater values than measurements, demonstrating that equation (3) and RETScreen computations overestimate actual solar radiation. H_{d_Vant} and H_{vant} are fairly correlated (r=0.36). If Njomo coefficients in equation (3) are updated, greater the correlation coefficient will be and better the Angstrom formula will be sustainable to estimate Maroua sunshine. Although values of H_{Vant} are slightly greater than those of H_{LRE}, their small correlation coefficient (r=0.20) shows that they do not have the same annual behavior. However, Amount of sunshine can present lot of variability according to the years, LRE and Maroua-Salak old measurements shall be completed by other years of recent data. In addition, this increase in the daily luminous intensity that reaches the earth surface, observed in Fig. 5, can be due to the variation of the atmospheric constituents. In Maroua there is no complimentary data such as LIDAR or atmospheric soundings to bring a clear answer. In the future, weather satellite data may be exploited to control atmosphere evolution and study its impact on the global radiation received on Maroua earth surface.

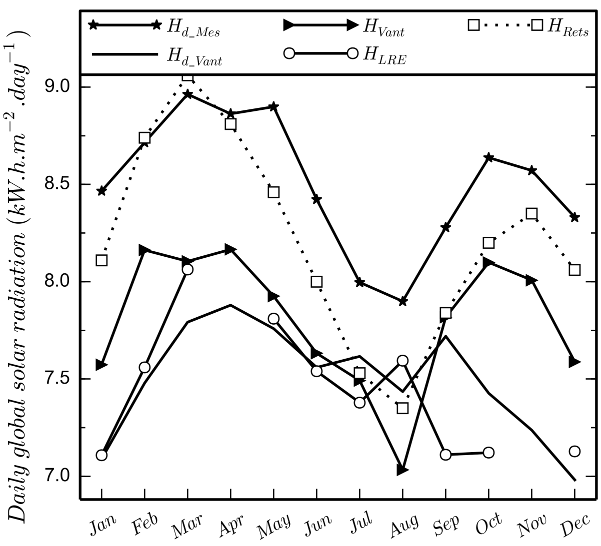


Fig. 5. Annual monthly average of daily global solar radiation in Maroua obtained by four methods

Table 2. Correlation coefficients between measured and estimated solar radiations

Regression equations $kW.h.m^{-2}/day$	r	s
$H_{Vant} = 0.88H_{d\ Mes} - 0.01$	0.87	0.16
$H_{Vant} = 0.44H_{d\ Vant} + 3.10$	0.36	0.36
$H_{Vant} = 0.29H_{LRE} + 4.22$	0.20	0.37
$H_{d\ Vant} = 0.29H_{d\ Mes} + 3.25$	0.35	0.25
$H_{\_Vant} = 0.59H_{\_Rets} + 1.95$	0.87	0.11

4.4. Determination of solar potential

The solar potential of the Maroua town has been determined with the help of four different sets of sunshine data. The results are reported in Table 3.. SD_{Mes} dataset is the largest (19 years) and the oldest of the town of Maroua. It provides the lowest solar potential in term of SD and the highest one in term of energy. But, as observed previously, these data should be taken with precaution. Solar potential obtained from LRE in 1984 was the unique solar radiation reference. Its one hour data interval is quite long and reduces the SD precision, and the comparison with VANTAGE measurements shows that it has to be updated. In addition, VANTAGE solar potential measurements done in 2014 show some differences from LRE ones. RETScreen software gives closer solar potential to VANTAGE one, even though VANTAGE has a reduced spectral range. Its database is constantly updated by NASA but the software does not calculate SD. Therefore for a rapid evaluation of Maroua solar potential, RETScreen software can be used but LRE and VANTAGE measurements give more realistic information. Although VANTAGE measurements were carried out just for one year, it is not enough to better characterize the area's sunshine. Thus, it is primordial to continue to carry out these measurements for several years in order to have a more satisfactory dataset allowing accurate knowledge of the current sunshine behavior.

Table 3. Four approaches for solar potential evaluation in Maroua. The first column represents the sunshine dataset type. Second and third column represent solar potential in term of SD: total annual and daily annual mean. Fourth and fifth columns are solar potential in term of energy: total annual and daily annual mean. Last column is the wavelength solar spectral range of the datasets.

	h/year	h/day	$kW.h.m^{-2}$ /year	$kW.h.m^{-2}$ /day	Spectral range (nm)
Maroua-Salak (1983-2005)	2908.08	7.97	2191.26	6.00	Solar spectrum
LRE (1984)	3530.76	9.65	1808.57	4.94	[285-2800]
VANTAGE (2014)	3490.87	9.57	1934.58	5.30	[300-1100]
RETScreen (NASA)	/	/	2080.50	5.70	Solar spectrum

5. Conclusion and Recommendations

From 1983 to 2005 in Maroua, according to the CSR, the annual monthly average daily SD was 7.97 hours, with a minimum of 6.14 hours in the month of August and a maximum of 8.96 hours in the month of November. An annual total of 2908.08 hours of SD was recorded, corresponding to 2191.26 kW.h.m^{-2}/year of solar energy. LRE reference solar database gives an annual solar potential of 3530.76 hours, equivalent to 1808.57 kW.h.m^{-2} for the year 1984. VANTAGE offers a better way to measure global solar radiation during the year 2014. It gave an annual monthly daily SD average of 9.57 hours, with a minimum of 8.81 hours recorded in August and a maximum of 9.90 hours in April. The total annual SD is 3490.87 hours, for a solar energy of 1934.58 kW.h.m^{-2}/year. Looking at the annual monthly mean for the different methods, it appears that the use of CSR in Maroua has leaded to considerably underestimate SD. Consequently equation (3) overestimates the resulting solar power. The solar potential obtained from VANTAGE is the most realistic and reliable, in concordance with value given by RETScreen software. The various sources of Maroua sunshine datasets are not totally in accordance. The data we have analyzed corresponds each of them to different years, they can thus be compared only statistically, and cannot give a clear answer to the sunshine. The best to do would be a new solar radiation measurement campaign, with new technological instruments. Once validated, these instruments have to be maintained in order to regularly update the solar database. The use of shorter measurement intervals has improved the detection of atmosphere turbidity variation. Sunshine evaluation in Maroua will also be improved by updating Njomo coefficients of Angstrom formula. In addition, the measurement of diffused solar radiation, cloud index and the aerosol optical thickness or satellite weather data can provide a better characterization and analysis of the Maroua town sunshine.

Nomenclature

H	Daily global solar radiation
n	Measured daily sunshine duration
N	Theoretical daily sunshine duration
H_0	Extra-atmospheric solar radiation
I_{cs}	Solar constant = 1367 W.m^{-2}
x	Number order of the day of the year
φ	Area latitude
δ	Solar declination angle
ω_s	Sunset angle
SD	Sunshine duration
SD_{Mes}	Monthly mean daily SD calculated from Maroua-Salak weather station SD measurements
SD_{LRE}	Monthly mean daily SD estimated from LRE solar radiation measurements
SD_{Vant}	Monthly mean daily SD estimated from VANTAGE solar radiation measurements
h_{Vant}	VANTAGE daily solar radiation
H_{d_Vant}	Monthly mean daily solar radiation computed with SD_{Vant}
H_{d_Mes}	Monthly mean daily solar radiation computed with SD_{Mes}
$H_{\_Rets}$	Monthly mean daily solar radiation computed by RETScreen International software
H_{LRE}	Monthly mean daily solar radiation measured by LRE
H_{Vant}	Monthly mean daily solar radiation measured by the VANTAGE
r	Correlation coefficient
s	Standard error of estimation

Acknowledgments

Grateful acknowledgements to Dr Nguetcho Tchakoutio Serge Aurelien and Mr Ali Zarma of Laboratoire Interdisciplinaire des Sciences et Sciences Appliquées du Sahel (LISSAS) as well as Mr Hamadou Toukour, in charge of Maroua-Salak weather station.

References

[1] Valérie NKUE and Donatien NJOMO : *Analyse du système économique camerounais dans une perspective de développement soutenable*. Revue de l'énergie, (588):102–116, mars-avril 2009.

[2] Donatien NJOMO : *Les solutions solaires aux besoins énergétiques prioritaires des populations rurales des pays en développement*. Revue de l'énergie, (404):498–503, juillet-août 1988.

[3] F. AYANGMA., E. G. NKENG, B. D. BONOMA and J NGANHOU. : *Evaluation du potentiel en énergie solaire au Cameroun : cas du nord Cameroun*. African Journal of Science and Technology, Vol. 9, No. 2, pp. 32–40, December 2008.

[4] T. T. Tefeu : *La filière des produits maraichers dans le Diamaré (extrême-nord-Cameroun)*. Master, ENS-Université de Maroua, 2013.

[5] N. Boukerzaza, A. Chaker and Z. Haddad : *Influence de l'irradiation globale sur les caractéristiques de fonctionnement d'un distillateur solaire*. Revue des Energies Renouvelables ICRESD-07 Tlemcen, pp 229 – 234, 2007.

[6] R. Mejdoul and M. Taqi: *The mean hourly global radiation prediction models investigation in two different climate regions in Morocco*, International Journal of Renewable Energy Research, Vol. 2, No. 4, 2012.

[7] Bayram Kilic, *Evaluating of Renewable Energy Potential in Turkey*, International Journal of Renewable Energy Research, Vol. 1, No. 4, pp. 259-264, 2011.

[8] Donatien NJOMO : *Modélisation des variations mensuelles de l'irradiation solaire reçue au Cameroun. Modeling, Simulation and control*, AMSE Press, vol. 18, No. 1, pp. 39–64, 1989.

[9] Leonard Nguimdo AKANA and Donatien NJOMO: *Spatial and temporal distributions of downwelling solar radiation in Cameroon as derived using a parameterized solar radiative transfer model in a molecular*

atmosphere. JP Journal of Heat and Mass Transfer, vol. 3, No. 2, pp. 73–93, 2009.

[10] Leonard Nguimdo AKANA and Donatien NJOMO: *Assessing the aerosol optical thickness in Cameroon using ground based solar radiation measurements*. American Scientific Publishers, Advanced Science Letters, vol. 3, No.2, pp 1–7, 2010.

[11] Augustin SIMO, Sylvie SIWE SIYAM and Hands BISSECK: *Mesure du rayonnement solaire au Cameroun*, janvier-juin1984.

[12] Augustin SIMO, Sylvie SIWE SIYAM and Hands BISSECK: *Mesure du rayonnement solaire au Cameroun*, juillet-décembre 1984.

[13] Davis Instruments: *http://www.davis-meteo.com/Vantage-Pro2.php*, 2014.08.29.

[14] Davis Instruments: http://*http://www.davis-meteo.com/capteur.php*, 2014.08.29.

[15] Retscreen international: *http://www.retscreen.net/*, 2015.03.09.

[16] A. S. Klein: *Calculation of monthly average insolation on tilted surfaces*. Solar Energy, vol. 19, pp. 32–329, 1977.

[17] Dorota Matuszko, *A comparison of sunshine duration records from the Campbell-Stokes sunshine recorder and CSD3 sunshine duration sensor*, Theoretical and Applied Climatology - Springer, Vol. 119, pp. 401–406, 2015.

[18] LP SD18 sensor: *http://www.deltaohm.com/ver2012/download/LP_SD18_D_fr.pdf*, 2014.