Covenant Journal of Physical and Life Sciences (CJPL) Vol. 1, No. 1 (Maiden Edition), August, 2013

Covenant University Journals

Global Solar Radiation Annual Profile, Causes and Seasonal Effects, at Ilorin, Nigeria

E.B. Babatunde
C.O. Akoshile
O.A. Falaiye &
T.B. Ajibola

Abstract:

The data of short-wave global (total) solar radiation of 4 years (1995-1998) at Ilorin (8˚ 34′ N, 4˚ 34′ E), Nigeria was used to study the characteristic behavior of SW- global solar radiation in the tropics. To do this, its weekly average was plotted and analyzed with respect to the atmospheric constituents responsible for the behavior. On the profile obtained, two "*Wells*" of unequal size and depth were identified; a "hill" and a "plateau" representing the potentials of the radiation were also identified *in a 52 - week year*. These features were associated with seasons of the year and the radiation potentials obtainable in the region. The size of the *Wells* indicates the time prevalence of the atmospheric constituents causing the Wells and the length of the respective season, while the depth indicates the amount and severity of the constituents. The "*Wells*" and the "*Plateau*" constitute 3 seasons in a 52- week year.

Keywords: solar radiation, radiation wells, radiation plateau, season.

1. INTRODUCTION

The SW-global (total) radiation, mostly between 0.2 and 4.0µm, was the main premise for the study because contained therein is the Photosynthetically Active Radiation (PAR) of wavelength range 0.4 to 0.7 µm, a wavelength region that is very important in the quantification of the Net Primary Productivity (NPP) of carbon dioxide (CO_2) in the total (CO_2) budget [1].

Ilorin *(8˚ 34′ N, 4˚ 34′ E),* Nigeria, the location of this study is in the Sub-Sahel Africa. It is close to the equator; about 350m above sea level and situated at the upper tip of the Guinea Savannah Zone [2]. Ilorin being in the tropics is annually under the spell of the North Easterly wind called Harmattan in the dry season, bringing with it the Sahara dust. The dust plumes which originate from the Bodel Depression in the Chad Basin [3] could be as thick as 3 km in depth, reducing visibility to less than 1 km. In the wet season, moist monsoon, known as South-westerly wind flows from the Gulf of Guinea into the area bringing rains and clouds. The atmospheric variables (dust, rains and cloud) are observed to have significant adverse effect of reducing the amount of radiation transmitted through the atmosphere to the ground surface; the sun-earth astronomical factors also affect the amount of the radiation received. Hence it is intended in this work to study the variation characteristics of the SW-global solar radiation received over 4 years (1995-1998), and analyze the effects of these meteorological parameters on the radiation with a view to obtaining a true representation of the recent annual profile of the SW-global solar radiation in the tropics.

2. DATA ACQUISITION AND PROCESSING

The SW-global radiation of wavelengths between 0.2 and 4.0 µm is measured on a continuous basis at Ilorin using an Eppley Precision Spectral Pyranometer (PSP), serial number *28866F3* and calibration constant of 8.2 x 10^{-6} V/m^{-2}. Its calibration is done every two years. In addition to the initial Eppley factory calibration, subsequent calibrations had been carried out at the Air Resources Laboratory in Boulder, Colorado, U.S.A., World Radiation Center (WRC) in Davos, Switzerland and *Eppley* Laboratory in 1999 [4]; other places include National Oceanic and Atmospheric Administration (NOAA), USA and other *Baseline Surface Radiation Network (BSRN)* campaigns.

Calibration was done using sun and sky irradiance under clear sky conditions. Flux was found to vary between 340 and 670 Wm^{-2} during calibration, and calibration constants were regularly updated.

In compliance with world WRR, sampling rate of 1-second duration was done every minute with an integration time of 3 minutes maintained for averaging and recording. The instrument was temperature compensated.

Data generated was stored in the CSI CR10 data logger before being transferred to dedicated computer and to a larger memory computer via an RS232 interface [5].

Data quality was ensured by eliminating spurious errors that could arise from incidental shading or partial un-shading of sensor by discarding all observations for which SW-global radiation is less than 20 Wm^{-2}.

In processing the data, the data assembled on minute-by-minute basis was used to generate the daily average data, which were in turn used to obtain the weekly and monthly averages. Because the sample points were large, about 480 in a day, grouping of data of several days were done, particularly on a weekly basis in the work.

The magnitude of the corresponding difference from year to year of the measurement was investigated, the values of the differences were found to be small. In fact, a function fit done for the difference values showed a sinusoidal trend of small amplitude and magnitude close to zero. This in essence indicates that there is no major departure from year to year values.

The weekly averages of the radiation was found to give new data points, which were closer to each other and presented more discernable trend. It was therefore reasonably assumed that the weekly representation of the measurement by its means over the four years, being fairly uniform, could be a good representative of the annual behavior.

3. RESULT AND ANALYSIS

Variation Characteristics of the SW-global radiation in the four year (1995-1998).

The graph of the annual daily average of the global (total) solar radiation of 4 years folded over each other is presented in Fig.1. Some features of the annual variation of the insolation are discernable, for example, two maxima and a minimum in between could be recognized, but their temporal locations are not distinctive.

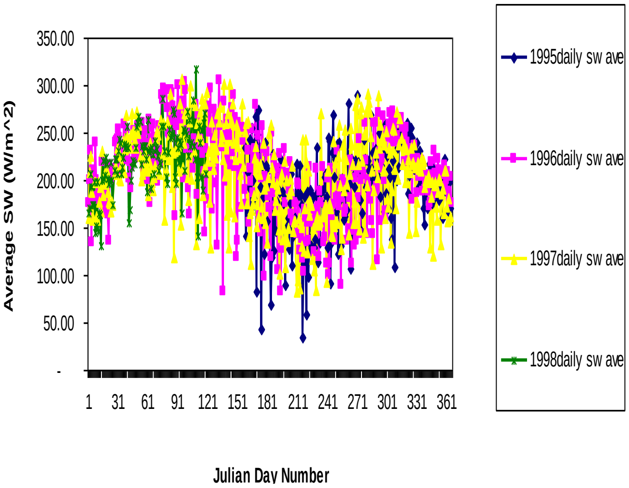

Figure 1: Annual Variation of the daily average of SW-radiation of 4years (1995-1998) folded over each other.

The monthly averages of the radiation obtained from the daily data of the 4 years were plotted in a stretch as in Fig.2. Repetitive features from year to year can be observed in the plot. In the figure the years end on months 12, 24, 36 and 48. Every year shows a sharp and narrow second maximum towards the end of the year. Each year also has 2 minima comprising of a high one at the beginning of the year between January and February and a very low one at the middle of the year about August.

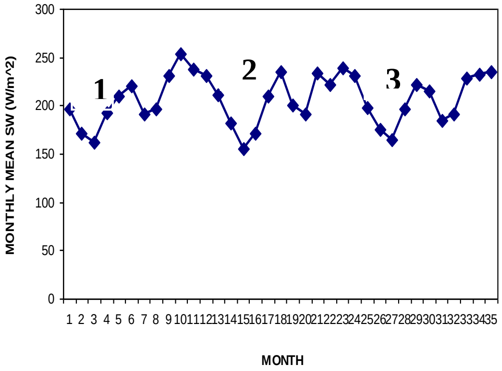

Figure. 2 Monthly average of SW- radiation of 4 years (1995-1998).

However, the weekly mean computed over the four years using segmented data fit, presented in Fig.3, gives very distinctive features of the annual weekly average of the radiation. It was assumed as adequately representing the mean plot of the measurement. The maxima and the minima and their temporal locations are sharply displayed. The figure gave a lot of insight into the potentials of the radiation, their temporal locations and the prevailing atmospheric or sky conditions associated with them. Fig.3 therefore represents the probable annual profile of the radiation measured over four years. It is observed generally from it that, in any year, the radiation plot has two of each significant maxima and minima with different magnitudes, confirming the findings of Babatunde and Aro [5].

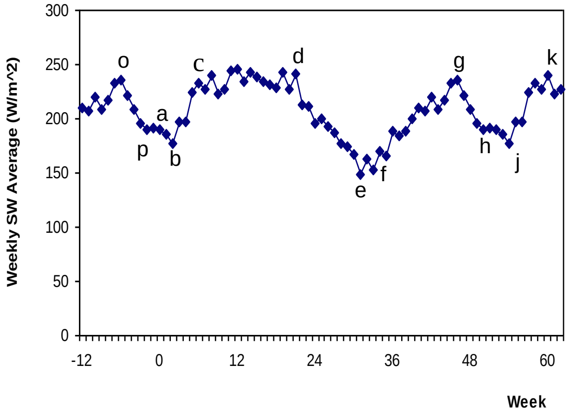

Figure 3 Plot of the Weekly average of SW-radiation for 4 years against the weeks of the year, for 1995-1998

Notable points on the graph in Fig.3 are thus labeled for detail analysis. For example, the extension **oa** and **ik** are to show trend continuity for the period immediately before the beginning of the year and after the ending of the year, hence points **a** and **i** represent the same points in the year. The calendar year starts at week **o** ending at week 52. There is a decline in SW transmission between November and January ending as evident in a minimum that occurred about the end of January. A second minimum occurred about August. The first minimum at **b** is in harmattan and the second minimum at **e** is in rain. The time duration between **o** and **c** is about 12 weeks while the duration between **d** and **g** is about 25 weeks.

The first maximum occurred at **c** and persisted to **d** lasting about 16 weeks while the second maximum at **g** is very short, lasting only 2 weeks. Between **c** and **d**, the SW transmission remains essentially constant with small fluctuations of less than 20 Wm^{-2} about a mean value of 235 Wm^{-2} from March to June. The drop in SW transmission between **o** and **b,** from about 230 to 175 Wm^{-2} lasted about 8 weeks with an average drop rate of -7.3 Wm^{-2} per week, which could be represented by a linear fit of for the region.

$$y = mx + c \quad \text{or} \quad y(Wm^{-2}) = -7.3x(wks) + c$$

where x is time in wks, c is a constant

Other regions similar to this can be represented by similar linear fit. The necessary parameters for the fits are presented in Table 1 (see Appendix). The drop from **o** to **p** was however more rapid, from 230 to 180 Wm^{-2} in 4 weeks at a rate of -11.5 Wm^{-2} per week. This rapid change, coupled with the low value of the relative humidity [6], has a severe effect on the health of animals, and stress on plants that causes them to shrink rapidly and change colour, promoting bush burning in the short time [7]. The green lush flourishing plant of October quickly emaciates to become grayish green and clayish brown in colour ready for rapid fire propagation by November ending.

The drop between **d** and **e** took about 10 weeks from the value of 241 to 153 Wm^{-2} at the rate of -9.3 Wm^{-2} per week, while the drop from **a** to **b** took a shorter time. The drop between **d** and **e** is deeper and took more than twice the time duration to occur. The increment between **b** and **c** in the SW transmission in the weeks 4 to 10 is from 176 to 233 Wm^{-2} per week, representing the rate of 9.5 Wm^{-2}. The second increment between **e** and **g** from week 32 to 48 at the rate 5.8 Wm^{-2} per week is a very gentle incremental rate occurring in the raining season. This means that the drop and rise when harmattan arrives and leaves are both sharp while those of the rains are gentle.

The overall annual behavior of the transmitted SW radiation at Ilorin is oscillating between a minimum at the beginning of the year and another at the end of the year with two maxima in between. This result could be understood as probably due to the position of Ilorin with respect to the movement of Inter-tropical Discontinuity (ITD).

4. DISCUSSION

Effects of the prevailing atmospheric constituents on the SW - radiation.

Between **o** and **b** which represents from December of the immediate past year to the end of January of the following year on the graph can be understood that dust is the major depleting agent of radiation in the atmosphere. The dust effect is depletion of solar radiation flux coming through the atmosphere to the earth's surface. The decrement from **o** to **b** is therefore attributable to harmattan dust while the decrement between **d** and **e** from about June to August is at the instance of clouds and the accompanying rains.

In the same vein, it can be said of the increment from **b** to **c** is attributable to reduction in the amount of harmattan dust in the atmosphere while the increment from **e** to **g** is at the instance of clouds and rain diminishing during the period. **ob** and **gj** represent the same period.

From the computed values of decrease and increase rates, the rates of decrease from **o** to **b,** about -7.3 Wm^{-2} per week and that from **d** to **e,** about and -9.3 Wm^{-2}per week are not the same; so also the rates of increase from **b** to **c,** about 9.5 Wm^{-2} per week and that from **e** to **g,** about 5.8 Wm^{-2} per week are not the same. The "hills" at **o** and **g** representing the same point of maximum potential of about 230 Wm^{-2} average, is lower than the maximum of about 235 Wm^{-2} average represented by the"plateau" (**cxd**). The "plateau" represents the major maximum energy potential occurring in March, April and May at a stretch, and the minor maximum occurring in November is represented by the "hill" at **o** or **g**. The major minimum represented by **ef** occurred in August, while the minor minimum represented by **ab** or **hj** occurred in December and January.

Therefore in a whole year of 52 weeks, there are two periods of maximum potential of the radiation, one major and one minor; two periods of minimum potential, one major and one minor as a result of the interaction of the atmosphere with the SW-radiation passing through, again confirming the findings of Babatunde and Aro [5].

4.1 The Radiation Flux "Wells"

Some of the results in this study can further be described and explained by two "Wells" and a "Plateau" experienced or observed on the radiation profile of Fig.3. Their existence is a clear indication of the effects of the atmospheric constituents, namely the dusts, clouds and rains on the incoming SW-radiation. They are therefore considered very important results of the study.

On the graph of Fig.3 two "gaps" are conspicuous. They are called "Radiation flux Wells". As observed, the Wells are neither of equal size nor of the same depth. The first Well is from **o** to **c,** i.e., from December of the immediate past year through February of the next year. It is called the "Harmattan radiation flux Well" and is about 12 weeks duration. The second Well is from **d** to **g,** that is, from June through November, which is about 25 weeks. It is called "Rain radiation flux Well". The duration of the Wells determines the "size" of the Wells while the "depth" of the Wells determines the severity of the dust or clouds on radiation in the respective season. The depth can therefore be a measure of the thickness (or influence) of the dust or clouds on the incoming radiation. Consequently therefore, in a 52-week year, not the calendar year, there are three seasons represented by:

(1) 1st "Well": Dry, dusty harmattan period (December of immediate past year to February of next year).
(2) The "Plateau": A period of mixture of dry, dusty air and moist air or light rainy or light wet season (March to May).
(3) 2nd "Well": Wet or heavy raining period (June to November).

4.2.1 The "Harmattan Well"

The "harmattan Well" represented by **o** to **c** is about 12 weeks wide and about 55 Wm^{-2} deep. It is explained to be the result of the interplay between the harmattan dust from Sahara and the incoming moist air of the South-westerly wind coupled with the presence of the Intercontinental Tropical Discontinuity (ITD). The Sahara dust originates from the Bodel Depression in the Chad basin [3], and is blown by the *North-easterly* winds every year to the region of the site of this investigation, Ilorin Nigeria West Africa. The *South-westerly* winds, the monsoon winds, bring cloud and rain to the region. At about the period of the "Well", the location of the Inter tropical discontinuity (ITD) is about the latitude of Ilorin [7]. ITD is the front or the boundary at which the North-easterly, warm and dusty air and the moist, cool South-westerly air meet and interact. ITD oscillates between about *5*° N in January and about *18*° N in July in the tropics. Hence by the implication of the presence of ITD, the high concentration of harmattan dust in the atmosphere with its dry hot air is expected at the location of the "Harmattan Well". The dust influence dominated throughout December and January reducing the amount of incoming radiation, a radiative transmission represented on the profile by **ob,** while in February, considerable amount of the dust is pushed away northward by ITD, and or absorbed by the moisture of the moist air, and consequently forming hygroscopic particles and cloud nuclei. The result is the relatively clearing of the dust off the sky and allowing radiation to penetrate the atmosphere in order to reach the ground surface. This radiative transmission is manifested in the rise (the segment **bc**) in the value of radiation recorded in February. The turning point at **ab** indicates the equilibrium reached between the dust influence and that of the moist air in clearing the air of dust and producing cloud cells.

4.2.2 "The Rain Well"

The "Well" is represented by **d** to **g** on the radiation plot profile in Fig. 3. It is about 25 weeks wide, from June through November, which actually is about the duration of the heavy raining season, and it is about 88 Wm^{-2} deep. Its existence is as a result of interplay between clouds, rain and warm dry air from the North, and also as a result of the presence of ITD at this period. The rains wash off the dust in the atmosphere allowing radiation to come in and at the same time the clouds blocking and reflecting the sunrays. However the rains and clouds completely dominated the atmosphere from about June through part of August as indicated by **de** in the figure, and resulting in depleting the incoming radiation considerably. However while the rain was washing off the dust, the dry hot air was interacting with clouds to disperse the clouds. The result of the interplay is the equilibrium attained at **ef** in August and the subsequent rise in the value of the incoming radiation as indicated by **eg** from September to November. The rise to the maximum value at **g** in November took 13 weeks. Again equilibrium is reached at **g** before the harmattan dust spell took over, when the ITD at this time is moving downward to the south, thus ushering in the harmattan dust.

4.2.3 "The Plateau"

At **c**, the incoming radiation reached its maximum value allowed by the interplay of dust, moist air and some cloud cells. The moist air presence is evident in the rise in value of relative humidity at this period. An equilibrium of the effects of the interplay of dust, moist air and some cloud cells is therefore reached at **c** in March. The equilibrium was dynamic as there were small fluctuations in the value of the incoming radiation but keeping the average value of the radiation at the "Plateau" value of 230 Wm^{-2} for 3 months, (March, April and May). The **plateau cxd** is thus a turning point and the benchmark optimal level for radiation attainable at this location.

The "plateau" value may therefore be regarded as a benchmark optimal level for shortwave solar radiation energy attainable at this location. And whatever value is obtained at any other time in the year can be considered a deviation from this optimal average value. The departure from this mean can be a measure of penetrability of the intermitting atmosphere by the intruder, like aerosol, or cloud or dust. Variations in the levels of the introduced intruders may create perturbations to the optimal level and may shift the level, depending on the degree of perturbations. Serious shifting of the equilibrium level however may adversely affect the Bio lives in the region [7].

5. The severity of the atmosphere constituents compared.

The rates of fall and rise of the radiation as caused by the two main atmospheric constituents, dust and clouds, were examined and compared. It is believed that the rate of decrease of radiation in the course of the year indicates the severity of the adverse effect of the atmospheric constituents responsible for the depletion of the radiation in the atmosphere. Hence since the rate of fall in the value of radiation as indicated by **de**, -9.3 Wm^{-2} per week during the raining and cloudy season is greater than the rate represented by **ab**, -7.3 Wm^{-2} per week during the harmattan dust season, it can be concluded that clouds and rain together have a greater devastating effect of radiation depleting than the dust. In other words the depletion of radiation by clouds and rain is more severe than that of dust. Similarly the rate of increase of radiation indicates how long the corresponding atmospheric depleting agents take to clear off the sky; hence it can be inferred that the effect of clouds and rains on radiation persists longer than that of harmattan dust as indicated by **eg**, 5.8 Wm^{-2} per week and **bc**, 9.5 Wm^{-2} per week respectively. This result also shows that clouds are not easily dispersed as dust is.

6. CONCLUSION

Shortwave global radiation observed over 4 years of measurement has been examined in this work. The weekly average of the flux varied between 150 and 250 Wm^{-2}. The weekly average temporal profile of the 4 years radiation has two "Wells", one "Plateau" and one "Hill". Three seasons were associated with these characteristics. One season corresponding to the first "Well" is the dry season from December to February, the second season to the "plateau" which is the early rain mixed with dryness from March to May, and the third to the second "Well" which is the cloudy and heavy raining season from June to November. The transition periods between the seasons are much shorter than the seasons, lasting maximum of 4 weeks and they are only one to two weeks long, and occurring as turning points on the profile.

References

[1] Daughtry,C.S.T. and K.P. Gallo, 1992. Spectral estimates of absorbed radiation and phytomass production in corn and soybean canopies. *Remote Sens. Environ.,39, pp 141-152.*

[2] Olaniran, O.J., 1991. Evidence of climatic change in Nigeria based on annual series of rainfall of different daily amounts, 1949-1985. *Climatic change, 19, pp 319-341.*

[3] Betrand, J.A., Cerf, A. and Domergue, J.K., 1979.Repartition in space and time of dust haze south of sahara. *W.M.D., 538,PP409-415.*

[4] Philipona, R., and Frohlich, C. 1995. Characterization of pyrgeometers and the accuracy of atmospheric long wave radiation measurements, Appl. Opt. 34, 1598-1605

[5] Babatunde, E.B., and T.O. Aro. 1990. Characteristics variation of Total(Global) solar radiation at Ilorin, *Nigeria. Nig. J.of Solar Energy, vol.9, pp 157-173*

[6] Ojo, O., 1977. The Climate of West Africa. *Heinemann, London. pp 219.*

[7] Babatunde, E.B. *et al.,* 2009. Observation bio-effect of SW-global solar radiation in Ilorin in the tropics. Advances in Space Research 43, 990-994.

[8] Akoshile, C.O. *et al.,* 2004. Proc. of the 5th international conference and 26th Annual General Meeting of the Nigerian institute of Agricultural Engineers, Vol. 26, pp 236-240.

About the Authors:

E.B. Babatunde[1*], C.O. Akoshile[2], O.A. Falaiye[2], T.B. Ajibola: [1]*Covenant University, Canaan Land, Ota, Nigeria* [2]*Department of Physics, University of Ilorin, Ilorin, Nigeria*

**Corresponding Author: ebbabatunde@yahoo.com.*