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Diurnal and Seasonal Variations of Global Solar Radiation at Akure, South-Western Nigeria

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Abstract: The diurnal and seasonal variations of mean Global radiation have been studied by analyzing two years data measured at the ground surface in a tropical station, Akure (7.150N, 5.120E), in Nigeria. The maximum mean Global solar radiation (which occurs around 14:00 LT) varies in the course of the year from 512 Wm^{-2} in the wet season (April-october) to 543 Wm^{-2} in the dry season (Nov-March). The low values (and large fluctuations) of the hourly mean values recorded during the wet season are attributed to the important roles that the convective clouds and water vapour play in the atmospheric radiation budget, which is very pronounced in the tropical areas of west Africa. The daily amplitude of the Global radiation is larger for the dry season (maximum in November) than it is for the wet season (maximum in July). A lag of about 2 h is also observed between the times when the maximum of the air temperature and the mean Global radiation courses occur over the area.

Key words: Global solar radiation, spectral irradiance

INTRODUCTION

A knowledge of spectral irradiance (direct and diffuse) arriving at the earth's surface is important for the design of many solar energy applications. For example, the quantity of total direct and diffuse radiation is needed in the calculations of heating and cooling loads in architecture and in the design of flat-plate collectors, etc. Also, a knowledge of direct radiation is needed in designing many concentrating systems. Furthermore, net radiation value is useful as an index for the classification of atmospheric stability in applied air pollution dispersion models.

Practical methods have been developed to estimate the net radiation with the help of astronomical and meteorological parameters routinely measured such as the solar elevation angle, sunshine duration hours, air temperature, wind speed, cloudiness and relative humidity. Many of such empirical relationships so obtained have relied on databases from geographical locations with different conditions to the tropics.

At present in the tropical parts of Africa, there is dearth of radiation data. The scanty radiation data available for the sub-region have been obtained mainly from some specific projects (e.g., HAPEX-Sahel experiment; Goutourbe *et al.*) undertaken at a few research stations and over a limited period.

Relevant theory: The sun is the star closest to the Earth and its radiant energy is practically the only source of energy that influences atmospheric motions and our climate. A significant proportion of the incoming solar radiation suffers depletion as it passes through the atmosphere by a combination of processes such as scattering and absorption by clouds, molecular species and aerosols[1,2] before reaching the ground and, depending on the nature of the surface (albedo), it is partly reflected and the rest is absorbed. The earth in turn emits the received energy in the infra-red region between 3 and 100 micrometer of the electromagnetic spectrum (longwave spectrum). Atmospheric constituents such as water vapour and low clouds absorb energy and re-emit the same partly downwards to the surface as long-wave radiation. Therefore, the net radiation represents the algebraic sum of the incoming and outgoing short-wave and long-wave radiative fluxes. Specifically, the knowledge of the net radiation provides important information about its component contribution to the available energy at the surface. The net radiation have been estimated from astronomical and meteorological parameters, which are routinely measured. Ironically, it is in tropical Africa where there is an abundance of solar radiant energy received all the year round that it is the least measured. The scanty radiation data presently available for the sub-region have been

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gathered mainly from specific projects undertaken at a few research stations. Therefore, in order to be able to model and validate land-surface energy exchange processes as accurate as possible for these areas, it is essential to establish a radiation databank. A number of researchers have contributed to the development of this field of study. For instance, experiments mounted in Obafemi Awolowo University, Ile-Ife[3] and OSU[4] have contributed significantly towards the establishment of a radiation databank in tropical Africa. The results of the measurements of Jegede[4] have shown, among others, that the dry months have comparatively larger values of the net radiation flux density than the wet months.

The purpose of this study therefore, is to make further contributions to the acquisition of radiation data by *in-situ* measurements at a different location in the tropic, Akure (7.150N, 5.120E). Also, a detailed study of the diurnal and seasonal variations of the Global radiation data performed over a period of two years will be reported.

MATERIALS AND METHODS

The radiation data that are being analyzed in this study are the hourly averaged values of the Global solar radiation at Akure, Nigeria. The site of the measurement is located at the old site of the Nigerian Television Authority, NTA Akure located a few kilometers from the city. The sensors are mounted close to the ground surface while the receiver (Console), together with the data-logger, is located in a measurement room adjacent to the location of the radiation sensors. The device used for the measurement is the Davis 6162 wireless Vantage Pro Plus, manufactured by Davis Instruments, Hayward, California, United States of America. It is equipped with the Integrated Sensor Suite (ISS), a solar panel (with an alternative battery power source) and wireless console, which provides the user interface, data display and analogue-to-digital conversion. The device uses the combination of fan-aspiration to minimize the effects of solar radiation induced temperature error. The ISS houses the external sensor array for measurements of pressure, temperature, relative humidity, UV index, solar radiation, rainfall rate among others. The console is connected to a computer through the data-logger from which the stored data are downloaded.

The current solar radiation measured (technically known as global solar radiation) is a measure of the intensity of the sun's radiation reaching a horizontal surface. This irradiance includes both the direct component from the sun and the reflected component from the rest of the sky. The solar radiation reading gives a measure of the amount of solar radiation hitting the solar radiation sensor at any given time, expressed in W m^{-2}

The measurements cover 24 h each day beginning from 00:00 h LT and data reading every hour. The data are transmitted by wireless radio to the data-logger attached to the console.

RESULTS AND DISCUSSION

Diurnal and seasonal variations of global solar radiation: The data used for this study is a part of the collection by *in-situ* measurements of meteorological parameters made from August 2003 to July 2005. The Global solar radiation determined in this study gives a measure of the amount of solar radiation hitting the "solar radiation sensor'' at any given time of the day. The equipment measures energy received in spectral band between 400 and 1100 nm. The measurement covered both main seasons occurring in Akure every year, i.e. the rainy season and the dry season. The rainy season months are from April to October, while the dry months are from November to March. The climate in Akure is tropical and is governed by the movement of the inter-tropical discontinuity, a zone where warm, moist air from the Atlantic converges with hot, dry and often dust-laden air from the Sahara known locally as the harmattan.

For the purpose of the discussion of results, morning hours is between 00:00 and 12:00 h LT, afternoon is from 12:00 to 16:00 h LT, while evening hours is from 16:00 to 20:00 h LT and night hours from 20:00 to 00:00 h LT.

The Global solar radiation value recorded in the morning hours increases steadily from zero to reach a maximum at about 1400 h LT. In the late afternoons, the radiation values decrease steadily to a minimum at about 1900 h LT and it remains constant throughout the evening hours. However, there are some remarkable seasonal differences in the mean diurnal variation of the global radiation in the individual months. The diurnal patterns in the dry months (Nov-March) are similar and they show some characteristic distinct features from those of the months within the wet season (April-October). The maximum of the daytime mean global radiation varies from 512 W m^{-2} in the wet season to 543 W m^{-2} in the dry season. The dry months have comparatively larger values of mean global radiation during the daytime (especially between 10:00 and 17:00 h) than the wet months (Fig. 1 and 2). Also, in some of the months studied there is a double peak of the mean Global radiation in the daytime. This feature is associated with diurnal variation of the convective clouds over the area, which attains a maximum at about the local noon and precipitates out shortly afterwards[4].

The diurnal patterns observed are similar except that the wet season has a lower daytime mean global radiation than the dry season Fig. 1. It can be argued that the

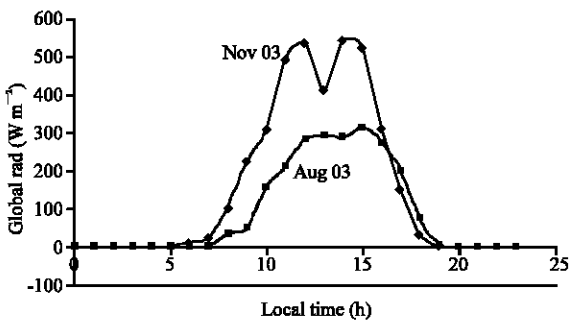

Fig. 1: Typical diurnal variation of the global radiation at Akure

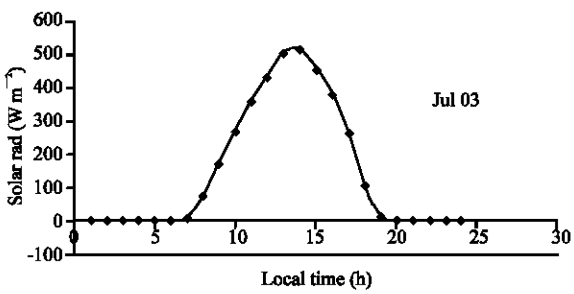

Fig. 2: Diurnal variation of the mean global solar radiation for July 2003

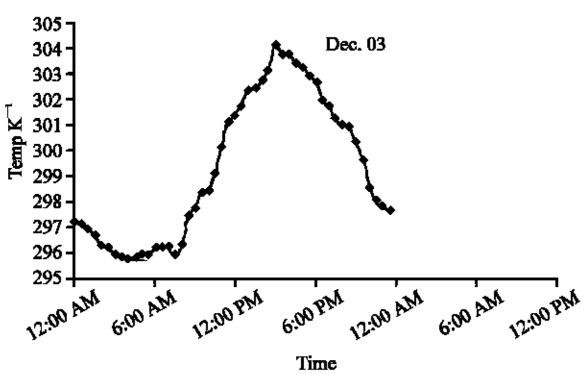

Fig. 3: Typical diurnal variation of the mean temperature at Akure

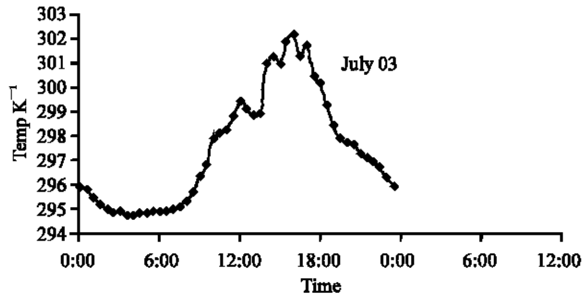

Fig. 4: Typical diurnal variation of the mean temperature at Akure

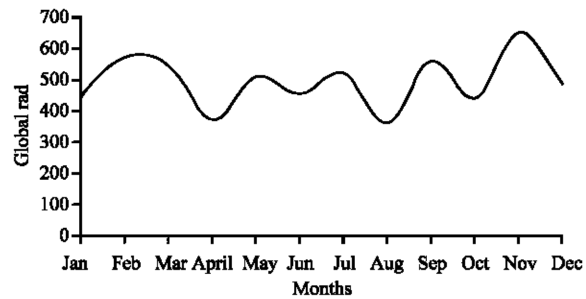

Fig. 5: Typical seasonal variation of global solar radiation

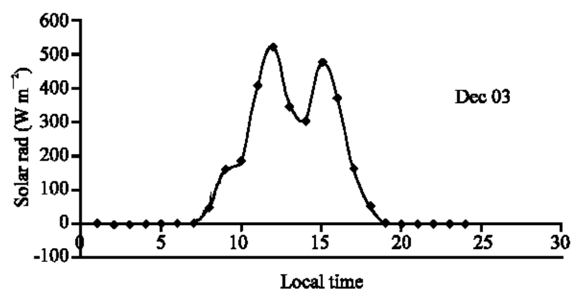

Fig. 6: Typical diurnal variation of the global solar radiation at akure

solar radiation is more affected by the clouds than by the hazy conditions of the harmattan dust spells. The attenuation of the direct beam is due to the presence of clouds in its path, as well as by the various elements of the cloudless atmosphere[1]. The depletion of the direct beam by the clouds depends on the type of clouds, their thickness and the number of layers. The diurnal variation of the mean global radiation can also be compared with the mean temperature measured at the same time Fig. 3 and 4. From the figures it is noticeable that there is a lag of about 2 h between the time when the maximum for the air temperature course occurs and when that of the global radiation course occurs. The time shift between the global radiation and air temperature observed in this study is due to the delay in heating the atmospheric column (which starts at the ground) by the in-coming solar radiation[5].

Seasonal variation of the global solar radiation: The seasonal differences Fig. 5 observed between the global radiation values can be attributed to the important roles that the clouds and water vapour play in the atmospheric radiation budget, which of course are very pronounced during the wet season in west Africa. The vigorous convective activities associated with the warm and moist monsoon flow that is prevalent during the wet months, lead to the formation of the cloud systems varying vastly on both spatial and temporal scales. The presence of convective clouds occurring within a highly humid atmosphere is mainly responsible for the marked reduction of intensive incoming solar radiant energy during the wet months.

From synoptic observations, there is little or no cloud cover (often of the patchy cirrus types) in the dry months and as such, it is expected that attenuation by clouds is minimal during the period. Also, the fluctuations which occur in the hourly averages of the wet months are in keeping with the large variability (spatial and temporal) of the cloudiness within the area[4].

It was observed that at night times, from January to December, the hourly values remain constant. However, in the daylight hours (especially between 1200 and 1500 h LT), there is an intensive annual variation of the global radiation values. The values show a maximum for both February (536 W m^{-2}) and November (608 Wm^{-2}) whereas a minimum occurs in August (336 Wm^{-2}), Fig. 5.

The dry months show a larger variations in the global radiation values compared with the wet months. The least diurnal variation (about 336 Wm^{-2}) is observed in August, while a maximum variation occur in November (608 Wm^{-2}) The need to determine quantitatively the amount of solar radiation incident on the earth's surface cannot be over emphasized. For example, solar radiation data would be useful for developing national programs on solar energy utilization required to assess the potentials of solar energy in a given region. Also, designers of thermal devices, such as flat-plate collectors or concentrating devices need to calculate hourly and daily values of the incident radiation. The photovoltaic engineers require an estimation of the spectral values of the direct plus diffuse solar radiation under cloudless skies, while the architects and engineers need to calculate thermal loads and natural illumination of buildings.

CONCLUSION

The diurnal and seasonal variations of the Global solar radiation measured at Akure Nigeria, a tropical location within the West African region, was analyzed and the main results can be summarized as follows:

- The seasonal variation of the Global radiation shows that the dry months have comparatively larger values than the wet months.
- The seasonal variations of the Global radiation values is mainly due to the attenuation of the in-coming solar radiation by clouds (during the wet season) and harmattan haze (during dry season).
- The solar radiation value increases from zero in the early morning to a maximum at about 1400hr LT in the afternoon, while the value decreases steadily to a minimum and a fairly constant value throughout the evening.
- A lag of about 2 h is observed between the times when the maxima for the air temperature course and the global solar radiation course occur over the area.

The present work constitutes our initial effort at making systematic empirical *in-situ* measurements of the Global solar radiation in the lower atmosphere in this part of the world. The plan is to continue the present measurements with a view of building a database of solar radiation data for radiation studies.

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