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# Measurements of net all-wave radiation at a tropical location, Ile-Ife, Nigeria

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RESUMEN

Se presentan datos de radiación neta en todas las longitudes de onda promediados cada hora, registrados en una estación meteorológica situada en el campus de la Universidad Obafemi Awolowo, Ile-Ife (7.52º N, 4.52º E), Nigeria, durante un periodo completo de tres años (2010-2012), para estudiar sus variaciones diurnas y estacionales. Esta información, obtenida con un radiómetro neto de alta sensibilidad de cuatro componentes, representa hasta hoy la información más consistente y detallada disponible para una localidad tropical de África Occidental. De acuerdo con los datos obtenidos, la radiación neta máxima ocurrió a las 14:00 LT (GMT + 1), y sus valores se incrementaron de manera considerable de 337.6 ± 146.4 $Wm^{-2}$ en julio, que es el pico de la estación lluviosa, a 441.7 ± 82.4 $Wm^{-2}$ durante marzo, en el final de la estación seca. En los meses de abril y octubre, que marcan el principio y fin de la estación lluviosa en Ile-Ife, se han registrado los valores más altos de radiación neta: 584.7 y 612.2 $Wm^{-2}$, respectivamente. Se observó una importante variación inter e intraestacional en los valores medios mensuales de radiación neta, debida principalmente a fluctuaciones de nubosidad y humedad. En el área de estudio, los datos revelaron la presencia de calentamiento radiativo neto en la superficie, cuya tendencia anual sigue una distribución bimodal. Los datos de este estudio respaldan los aportados por otros autores.

ABSTRACT

Hourly averaged net all-wave radiation data spanning a complete three-year period (2010-2012) at a meteorological station located inside the Obafemi Awolowo University campus in Ile-Ife (7.52º N, 4.52º E), Nigeria is presented in this study to investigate its diurnal and seasonal variations. Using a high-sensitivity four-component net radiometer, the data represents so far the most consistent and detailed information available for a tropical location in West Africa. From the dataset, hourly maxima of the net radiation occurred at 14:00 LT (GMT + 1), whose values increased considerably from 337.6 ± 146.4 $Wm^{-2}$ in July, which is the peak of the wet season, to 441.7 ± 82.4 $Wm^{-2}$ in March, the end of the dry season. April and October, both of which mark the beginning and end of the raining season at Ile-Ife have recorded the highest values of 584.7 and 612.2 $Wm^{-2}$, respectively. There was strong intra/inter-seasonal variation observed in the monthly mean values of the net radiation due mainly to the fluctuations in cloudiness and humidity. In the study area, the data indicated a net radiative heating taking place at the surface, whose annual trend follows a bimodal distribution. The present data supports the results published in earlier studies by other authors.

**Keywords:** Tropical wet and dry; Ile-Ife, Nigeria, net radiation; bare soil, intra/inter-seasonal variations, radiative heating.

## 1. Introduction

The importance of reliable and continuous measurements of net all-wave radiation at the land surface cannot be overemphasized for fundamental research and applications in meteorology, as it determines the total amount of energy available for physical and biological processes such as evapotranspiration, air and soil warming. Particularly, net radiation data is required for modeling mass and energy exchange processes between the atmosphere and land surface (Arya, 1988; Iziomon *et al.,* 2000; Foken 2008a).

Net all-wave radiation at the surface can be determined as the algebraic sum of incoming and outgoing solar (shortwave, 0.15-4 μm) and atmospheric (longwave, 3-100 μm) radiation, which is expressed symbolically as:

$$R_N = R_S\downarrow + R_S\uparrow + R_L\uparrow + R_L\downarrow \qquad (1)$$

where $R_N$ is the net (all-wave) radiation, $R_S\downarrow$ is the in-coming shortwave (or solar) radiation, $R_S\uparrow$ is the out- going (reflected) shortwave radiation, $R_L\uparrow$ is the incoming long-wave (sky) radiation and $R_L\downarrow$ is the outgoing (terrestrial) longwave radiation. $R_S\downarrow$ is calculated from the sum of the horizontal beam and diffuse solar radiation (termed global radiation). The outgoing shortwave radiation $R_S\uparrow$ is determined as the fraction of incoming radiation, which is reflected by the surface, that is,

$$R_S\uparrow = a\, R_S\downarrow \qquad (2)$$

where *a* is the surface reflection coefficient, which is termed albedo. Values of this parameter depend on the surface cover type, color, textural characteristics and wetness degree. Typically, for vegetative surfaces the value is between 0.16 for long grass and 0.25 for agricultural lands. Over bare soil surfaces, the range is between 0.05 for wet fallow field and 0.45 for dry sand (Arnfield, 1975; Arya, 1988).

The outgoing (terrestrial) longwave radiation, $R_L\uparrow$ is given as a function of the fourth power of the surface temperature (the Stefan-Boltzmann's law). As such, $R_L\uparrow$ shows a strong diurnal variation over most natural surfaces. Of the incoming longwave radiation, $R_L\downarrow$ is found to be dependent primarily on temperature inhomogeneities in the boundary layer because of the high concentrations of water vapor and carbon dioxide, both of which are strong emitters of infrared (thermal) radiation (Viudez-Mora, 2011). Both longwave radiation components, $R_L\uparrow$ and $R_L\downarrow$, are nearly of the same magnitude; hence the values of longwave radiation balance at the surface are usually small (Smith and Rutan, 2003).

Net all-wave radiation $R_N$ measured at the surface, which is given by Eq. (1.), has distinctly contrasting values for daytime and nighttime conditions due to the absence/presence of solar radiation. In sub-tropical areas, due to the high intensity of incoming solar radiation (which is about 1000 $Wm^{-2}$ at the local noon), the ratio of net longwave radiation ($R_L = R_L\downarrow + R_L\uparrow$) to net shortwave radiation ($R_S = R_S\downarrow + R_S\uparrow$), which depends on the degree of cloudiness, is roughly about 0.05 to 0.2 (Jegede, 1997a; Alados *et al.,* 2003; Matuszko, 2012). At nighttime, due to the absence of insolation, the terms representing shortwave radiation are absent, so that $R_S = 0$. Therefore,

$$R_N = \begin{cases} \{0.80 \sim 0.95\}\ R_S & (Daytime) \\ R_L & (Nightime) \end{cases}$$

The measured net radiation is dependent on geographical location, time of the day, season, cloudiness, surface temperature, and type and conditions of the surface as indicated by albedo and emissivity (Augustine and Dutton, 2013; Matzinger *et al.,* 2003). Due to the fleeting nature of convective clouds and the highly humid conditions commonly occurring in tropical areas, there is a preponderance of the short-period (< 1 min) fluctuations superimposed on the mean net radiation (Jegede *et al.,* 2006; Kothe and Ahrens, 2010). There are several empirical relationships that can be used to estimate net radiation from routinely measured meteorological data including air temperature, insolation, cloudiness and relative humidity (e.g. Nielsen *et al.,* 1981; Amarakoon and Chen, 1999). A major disadvantage is that these empirical relationships are not accurate enough for sensitivity tests in the modeling of surface energy exchange processes (Alados *et al.,* 2003).

In the present study, continuous measurements of hourly-averaged net radiation data for Ile-Ife (7.52º N latitude, 4.52º E longitude), Nigeria by a four-component net radiometer (model NR01) recorded over a period of three years (2010-2012) have been utilized for investigating temporal variations at a particular site located in a tropical area.

## 2. Net radiation at low latitudes in West Africa

In continental areas of West Africa below 15º N latitude, the sun is always high up in the sky at the local noon. The seasonal weather pattern is determined primarily by the latitudinal position of the inter-tropical discontinuity (ITD) line. The ITD line is where the moist southwesterly current, which originates