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Downward longwave radiation categories in Nigeria

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ABSTRACT

Downward longwave radiation (DLR) can be regarded as the best meteorological parameter for describing the climate of a region, and it also affects the energy at the surface of the earth. In this study, DLR in Nigeria was categorized using descriptive statistics of 22 years of satellite-derived daily data spanning from July 1983 to June 2005. Also, the Mann Kendall non-parametric test was used to evaluate the long-term trends of the radiation. The country can be split into three DLR zones (northern, mid and coastal regions). On average, the northern regions are generally characterised by low radiation with large variations in DLR showing that the regions have harsh weather conditions. The southern coastal regions on the other hand are found to be characterised by high radiation levels with small variations, which implies that their climate is relatively stable. The mid regions between the far north and southern coastal regions have moderate radiation levels, with corresponding moderate ranges. Across Nigeria, heavy rainfall locations have high DLR and latitude is the best geographical parameter that consistently influences most categories of DLR. Also, longitude has slight inverse variation with daily mean DLR, probably reflecting the decreasing strength of the south easterly wind that flows toward the longitudinal east during the rainy season. Around locations of neighbouring latitudes, water body influences DLR more than elevation. At 95% confidence level, annual and rainy seasons decreasing significant trends for DLR were found in the northern parts of the study area. DLR variations with season, latitude, elevation, and closeness to water bodies were confirmed. In conclusion, parameters such as latitude, elevation, longitude (or wind direction), water bodies and rainfall, that when varying would affect atmospheric water vapour, temperature and cloudiness, in turn influence DLR.

1. Introduction

The earth's surface is affected by two main types of radiation namely shortwave and longwave. Shortwave radiation otherwise regarded as global (or total) solar radiation is the radiation received from the sun and is composed of both the beam (or direct) and diffuse radiations. While beam radiation reaches the earth's surface directly from the sun after travelling through space, diffuse radiation is subjected to interference from any interspatial matter (Mani, 1980; Spitters et al., 1986; Kumar et al., 1997). Global solar radiation from the sun through the atmosphere, which has a wavelength range of 0.29 to 3.9 μm, accounts for a part of the entire radiation incident on the earth's surface. The other part is longwave radiation, which falls into the range of 4 to approximately 50 μm and reaches the surface of the earth via contributions from the atmosphere and the sun's spectrum (Kiehl and Trenberth, 1997; Wild et al., 2013). Majority of longwave radiation falling on the surface of the earth is from the atmosphere. And apart from absorbing it from the sun, also the atmosphere derives longwave radiation through radiative transmittance of global solar radiation (Igbal, 1983; Savijarvi, 1990; Trenberth et al., 2009). When the direction of atmospheric longwave radiation is down, then it is referred to as

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downward longwave radiation (DLR). Otherwise, the longwave radiation emitted from the surface of the earth and moving up is termed upward longwave radiation. Additionally, there is net longwave radiation, which is the difference between the downward and upward longwave radiations. Gases that account for DLR in the atmosphere include water molecule (H_2O), carbon dioxide (CO_2), ozone (O_3), nitrous oxide (N_2O), carbon monoxide (CO), oxygen (O_2), methane (CH_4), and nitrogen (N_2). The nature of the interaction between DLR and these gases and aerosols is dependent on the type of atmosphere, and the major absorbers of DLR are water molecules (Igbal, 1983; Niemela et al., 2001; Cotton et al., 2010; Liang et al., 2012).

Global solar radiation can only be received during a certain period of the day, though it is more energetic due to its smaller wavelengths, however, DLR is received constantly. DLR is thermal in nature (by virtue of its wavelength) and hence accounts for the heat content of the earth's atmosphere. According to Soares et al. (2004), DLR data can be used as surrogate for cloud cover data and the radiation is a better predictor of the climatic features of a region than any other meteorological parameter (such as temperature, water vapour pressure or relative humidity).

DLR is a part of the net longwave radiation, which is defined as

$$R_n = S_n + L_n = DSR - USR + DLR - ULR \tag{1}$$

where R_n is the net radiation, S_n is the net shortwave radiation, L_n is the net longwave radiation, DSR is the downward shortwave radiation, USR is the upward shortwave radiation, DLR is the downward longwave radiation and ULR is the upward longwave radiation. Note that USR and ULR do not directly come from the sun, and are secondary because of the consequences of reflection at the earth's surface (Ohmura, 2001).

Thus, DLR is a constituent of the surface energy of the earth's radiation budget. It is an essential variable in forecasting models and when evaluating climate change. Furthermore, DLR has a large influence on greenhouse gas-forced surface warming via its relationship with water vapour (IPCC, 1996; Allan and Slingo, 1998). DLR is directly linked to the radiative cooling of the atmosphere, which is associated with the atmospheric hydrological cycle (Allan, 2006). Therefore, accurate methods for calculating and simulating DLR are required, because of its role in climate models (in the form of radiant energy from ocean dynamics) (John et al., 1997). However, this is not easy, because of a lack of atmospheric temperature and humidity profiles that are required for numerical or graphical solutions to Schwarzchild's equation (Goody, 1964).

DLR can be directly measured using a pyrgeometer. These are expensive and highly delicate instruments, which require constant cleaning, shading, and ventilation. In some instances, corrections must be made for the heating or cooling effects of the dome to ensure optimum precision. Furthermore, pyrgeometers must be regularly calibrated at least every 2 years to avoid malfunctions. However, there are no calibration standards because the instruments' components undergo changes that require diverse testing methods. Although researchers have regularly attempted to standardize and generally improve pyrgeometers, the field responses of calibrated pyrgeometers are distinct from laboratory observations, which is a major limitation (Duarte et al., 2006; Wang and Dickinson, 2013). These issues mean that pyrgeometers are only used by experts, and they are not available in most weather stations. Furthermore, if they are available there are instances of missing data.

A satellite can also be used to acquire the required data. This tends to solve the problem of data scarcity, particularly concerning longevity and the simultaneous coverage of many locations. Satellite data also have associated problems. Briefly, the main issues that affect satellite methods are related to retrieval methods and procedures for calculating DLR from satellite images. These issues lead to differences in the readings from different satellites for the same locations. As a result, DLR data from satellites are associated with varying degrees of accuracy (Ellington, 1995; Nussbaumer and Pinker, 2012). Reanalysis methods are another important source of DLR data, which, in most cases, use satellite data as input.

Previous studies at the University of Ilorin have established that DLR patterns in Nigeria, Ilorin is seasonally dependent, and there are only small differences between the dry and rainy seasons (Miskolczi et al., 1997; Udo and Aro, 1999). At present, this site remains the only known location for ground measurements in Nigeria. Data from the site have been combined with data from other parts of the globe and used as inputs for a global data reanalysis (Wild et al., 2001; Morcrette, 2002; Wild et al., 2013). To the best of our knowledge, no other location in Nigeria has a DLR pattern that has been so well established. Hence, our objective is to characterise DLR across Nigeria using satellite data, by examining its trends and relationships with geographical parameters namely latitude, elevation, longitude and water bodies. However, due to the lack of quantitative data on water bodies, a meteorological parameter, rainfall is also used in the analysis with DLR. This information may have many applications in areas such as agriculture and plant husbandry. For example, if the radiation regime of a location is replicated via the greenhouse effect, then plants that are found in such a regime can be cultivated elsewhere. Under unfavourable weather conditions, crop farming has been improved using scientific knowledge and DLR data (Lhomme and Vacher, 2002; Yin et al., 2008).

1.1. Study Area

The area under investigation is shown in Fig. 1. Geographically and politically, Nigeria is primarily divided into the north and the south, and is further divided into six geopolitical zones (north-east, north-west, north-central, south-east, south-west, and south-south). There are 36 states in Nigeria, excluding Abuja, the Federal Capital Territory, which is the capital and is situated in the centre of the country. The country occupies a total area of 923,768 km^2, and 13,000 km^2 is covered with water (Adesopo and Asaju, 2004; Obiora, 2008).

Lying around the equatorial region, Nigeria is a tropical country that has two main seasons: the dry season and the rainy season. However, there is a third season known as the Harmattan season, which is a cloudy and dusty period that can be regarded as a subset of the dry season. Additionally, the country witnesses the 'August break', which is a small dry period or reduction in rainfall that