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Periodicity of Downward Longwave Radiation at an Equatorial Location

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Abstract

A good understanding of the diverse mechanisms in the atmosphere is required in modelling the climate. In this study, the diurnal and seasonal patterns of all-sky downward longwave radiation (DLR) at Ilorin (8^o 32^l N, 4^o 34^l E), Nigeria were investigated alongside relative humidity (RH) and temperature. The average diurnal pattern of DLR gives an arc that begins by increasing gradually with some inherent fluctuations from 01:00 hour to a maximum at 14:00 hour local time, and then gradually decreases to a minimum at 00:00 hour. However, sometimes erratic and double peak arc diurnal DLR patterns occur around the mid and the end of the year periods respectively. The seasonal, diurnal peak of temperature and the minimum of relative humidity (RH) occur approximately two hours after the peak of DLR. Besides, the seasonal trends of both DLR and RH match each other, except sometimes in June, which could be due to the midyear DLR erratic diurnal effect. Possibly, the mechanisms of the inter-tropical discontinuity (ITD) influence the particular diurnal patterns of DLR at the midyear and year-end periods. Moreover, monthly dispersion of DLR is high during known months of high atmospheric aerosols, and annual maximum temperature occurs after the Harmattan season. Hence, variations in DLR are influenced mostly by mineral dust in the atmosphere, mechanisms of ITD and changes in the sun-earth distance, which reflects on the different seasons in Ilorin.

Keywords: Downward longwave radiation (DLR); Temperature; Relative humidity; Inter-tropical discontinuity (ITD); Sun-earth distance.

1. Introduction

To some extent, atmospheric heat levels are controlled by downward longwave radiation (DLR), such that without the radiation, the average global temperature of the atmosphere could be 30 - 40 °C lower (Sellers, 1965). In temperate regions, the energy contribution from DLR in the melting of snow is vital and could surpass that of total solar radiation under cloudy skies (Ohmura, 2001; Sicart et al., 2006). Low DLR in those regions sets off temperature inversion and frost formation, and the radiation is one of the critical components of the net radiation budget of the earth's surface (Jordan and Smith, 1994; Wild et al., 2004). The knowledge of DLR is required in evaluating the global hydrological cycle in climate models, agriculture, energy balance calculations of building cooling systems, solar collectors, weather and climate forecasting (Stanhill et al., 1966; Catalanotti et al., 1975; L'homme and Guilioni, 2004; Tang et al., 2007).

Total solar radiation, which is a major radiant energy that drives some processes on the earth, is received directly from the sun, whereas DLR is mainly a secondary radiation emitted by atmospheric grey bodies or gases such as H_2O, CO_2, O_3, N_2O, CH_4 and CFC's (Niemela et al., 2001; Wang and Liang, 2009; Igbal, 1983). DLR is influenced by cloudiness, temperature and humidity (or water vapour) of the atmosphere and it varies with latitude, elevation, longitude and vegetation cover (Obot et al., 2018; Naud et al., 2013; Wang and Liang, 2009; Iziomon et al., 2003). Furthermore, the radiation can be used as a proxy for cloud cover, and it is an efficient indicator of the climate of any given region (Soares et al., 2004). Presently, climate change is of major concern and DLR can be used to evaluate it (Wild et al., 2001; Stephens et al., 2012).

The characteristics of atmospheric parameters differ from one region to another on the globe. For instance, the temperate regions experience snow at certain period while in some parts of the tropics like Nigeria, Harmattan season occurs, which is

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associated with poor visibility and high aerosol content (Adedokun et al., 1989; Sicart et al., 2006; Anuforom et al., 2007). Two major air masses linked with the two main seasons, blow across Nigeria and other West African countries: the south-westerly flow of the rainy season and the north-easterly flow of the dry season. The boundary between the cool and moist air of the rainy season and the hot and dry air of the dry season is the inter-tropical discontinuity (ITD); and together with other factors like closeness to the Atlantic Ocean and latitude, the position of ITD over a given location is also linked to the magnitude of rainfall (Ilesanmi, 1971; Adejuwon, 2011).

The mineral deposited dusty wind of the Harmattan season originates from the Sahara Desert, though, the dominant wind of the rainy season originates from the Atlantic Ocean. Apart from contamination of water bodies, the circulating aerosol-laden air during the Harmattan negatively affects the eyes and lungs and accounts for other diseases as well. Besides, the dusty wind is often transported from one continent to another, and it impacts on soil nutrients and alters the dynamics of the land-sea–current exchange (Schwanghart and Schutt, 2008; Goudie and Middleton, 1992).

While the values of DLR are large around the equator, they are small at the Polar Regions, and via atmospheric and water currents exchange between the equator and the poles, global heat balance is sustained (Martzke and Scott, 1999; Wild et al., 2001). Hence, because of the interconnectivity between different regions on the globe, it is important to intensify the study of the trends of the radiation over every part of the world, both for short and long terms, for a better understanding of the atmospheric dynamics.

Globally, there are few ground measurements of DLR because the instrument, pyrgeometer, is relatively expensive, delicate and requires calibration when used within six months to two years. Even though the radiation has been measured and analysed in many locations around the world, yet few studies have been reported in Africa (Udo, 2004). Besides, studies conducted in Africa make use of small durations of measured data (Culf and Gash, 1993; Jonsson et al., 2006). However, valid conclusions are rarely drawn from short duration studies because at times atmospheric irregularities occur probably as a result of thunder or solar storms that induce uncommon effects in the atmosphere (Dickinson, 1975; Schlegel et al., 2001).

DLR has been analysed in Ilorin (8^o 32^l N, 4^o 34^l E), Nigeria more than any other stations in Africa. Based on measurement from September 1992 to August 1994, the average patterns of the radiation were found to be high during the rainy season and low during the dry season (Miskolczi et al., 1997; Udo and Aro, 1999; Udo and Aro, 2000). Other obtained results from the same data set include that the radiation is more dependent on moisture than the state of the skies and the amplitude of variation is seasonal (Udo, 2004). Moreover, there is a good relationship between DLR and the ratio of photosynthetically–active radiation (PAR) to global solar radiation (Udo and Aro, 2000). Additionally, empirical models for DLR based on temperature, relative humidity and water vapour pressure have been obtained from the same data set (Udo, 2003). However, to the best of our knowledge, no study has analysed the characteristics of DLR in Ilorin, Nigeria beyond the mentioned two years. This study aims to investigate further the trends of all-sky DLR in Ilorin, Nigeria using longer data of approximately five and a half years. Uniquely, the diurnal and seasonal patterns of DLR would be compared with those of temperature and relative humidity. Furthermore, for the first time, possible Harmattan effect on the radiation would be examined. Inputs from this site have been included in global analyses of DLR (Wild et al., 2001; Morcrette, 2002; Wild et al., 2013), and it is expected that the results obtained in this study would also be useful for climate studies and modelling.

2. Methodology

The site used in this study is Ilorin (8^o 32^l N, 4^o 34^l E) and it remains the only known station in Nigeria where ground measurements of DLR have been done, which were from August 1992 to September

1994 and July 1995 to March 1998. However, incomplete data of June 1995 and April 1998 are also available; therefore, sometimes those two months were not included in some of the analyses. Apart from DLR, records of temperature and relative humidity (RH) for July 1995 to March 1998 were also downloaded from the Baseline Surface Radiation Networks (BSRN) website (https://www.pangaea.de/PHP/BSRN_Status.php). Ilorin is one of the 52 BSRN global stations (Ohmura et al., 1998; Konig-Langlo and Sieger, 2013). Reportedly, the site has two major seasons which are the dry season (November to February) and the rainy season (March to October). However, there is a minor season known as Harmattan, a period of extremely dry air and poor visibility due to its associated high mineral dust content. The Harmattan period could last for about two months within the dry season, and its windy dust comes from the Bodel Depression in the Chad Republic (Miskolczi et al., 1997; Udo and Aro, 1999). Besides, other information on model and calibration of instrumentation and data treatment have been previously reported (Miskolczi et al., 1997; Philipona et al., 1995; Philipona et al., 2001; Udo, 2000; Udo, 2004). Obtained data for the site were recorded in the two-minute interval from August 1992 – September 1994 and in the three-minute interval from July 1995 – March 1998. Furthermore, DRL, temperature and RH data in minutes were reduced to hourly and monthly values.

To understand the characteristics of DLR in Ilorin, the diurnal patterns for the all-sky downward longwave radiation during the monthly, dry and rainy seasons, solstices and equinoxes periods were examined. At times, they were compared with corresponding patterns of temperature and RH. Furthermore, the monthly variation of the radiation was determined using the robust statistical dispersion method of median absolute deviation (MAD) given as:

$$MAD = Median\,([DLR_i - Median\,(DLR_i)]) \qquad (1)$$

Where DLR_i is the respective hourly value of DLR at the ith hour.

3. Results

3.1. Diurnal pattern of DLR

The average diurnal pattern of DLR for Ilorin was found to increase gradually (with some inherent fluctuations) from 01:00 to a maximum around 14:00 hour local time, and then gradually decreased to a minimum (Figure 1a). During the rainy season (Figure 1b), DLR showed the same pattern as described above, though the values were much higher and the pattern was maintained during the dry season (Figure 1c) but at lower values. During the four important solar periods, the September equinox diurnal DLR (Figure 2a) is similar to the existing pattern, whereas in the March equinox (Figure 2b) the radiation maintains almost a steady value from 01:00 to 07:00 hours before starting to increase from 08:00 hour and thereafter follows the normal pattern. However, comparing the diurnal DLR for the two equinoxes, one seems to be a lateral inversion of the other. While the radiation is lower at the beginning hours of the day than at the ending hours for the March equinox, the situation is reversed for the September equinox. Different scenarios were observed during the months of June and December solstices. Examining the June solstice (Figure 2c), the values are rather low, even lower than the dry season (Figure 2d), even though June is part of the rainy season with typically high DLR values. The December solstice produced a cyclic pattern within a 24-hour period, as seen in Figure 2d; it increases from 01:00 hour to the 06:00 hour, dims slightly from 07:00 to 10:00 hours, rises until 15:00 hour, and then gradually decreases to a minimum.

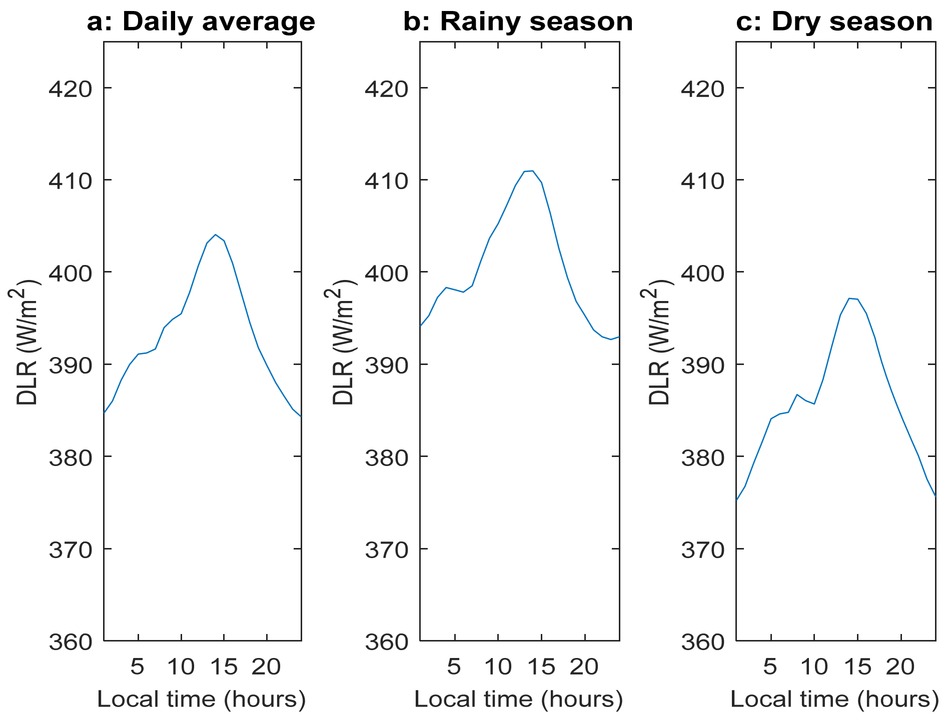

Figure 1. Average diurnal patterns of DLR at Ilorin between July 1995 and June 1997.

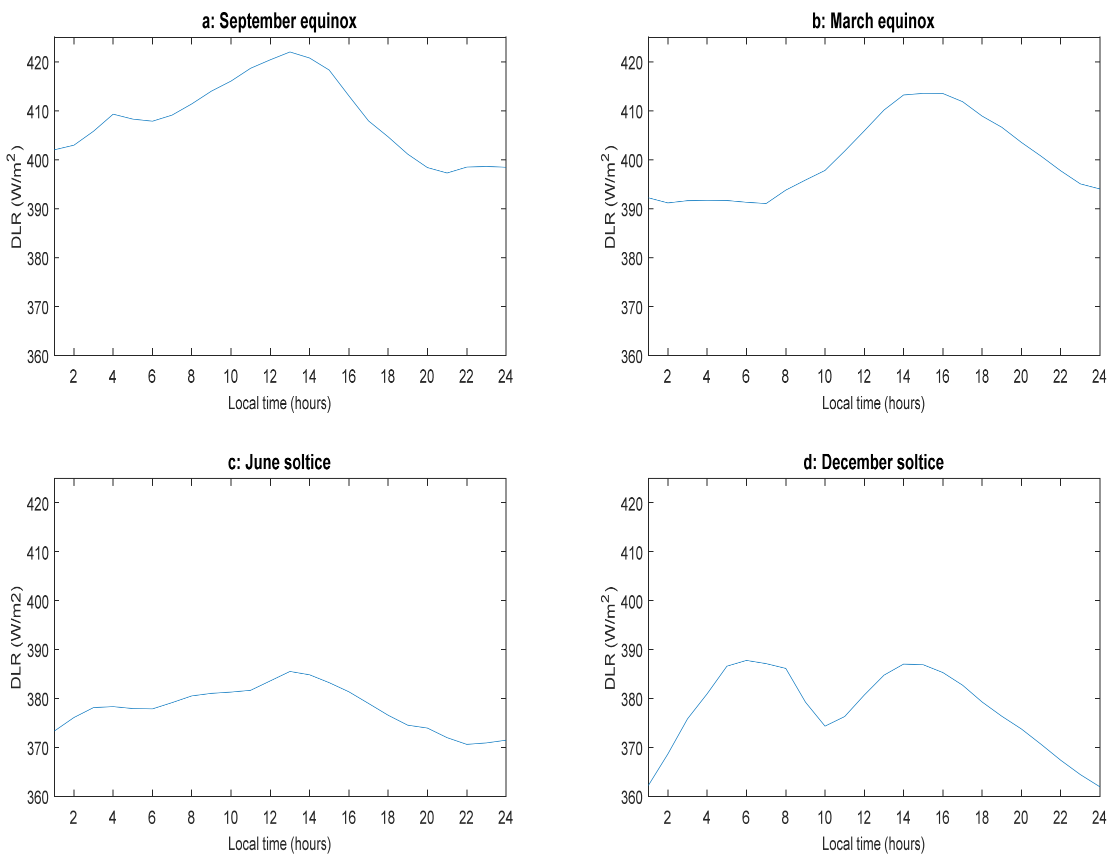

Figure 2. Monthly diurnal patterns of DLR during the important solar months at Ilorin for periods between July 1995 and June 1997.

In order to further examine the uncommon patterns of the two diurnal extremes witnessed during June and December, all diurnal DRL data around and including those affected two months of June and December are also analysed. When all the graphs of the months of June were examined, it was discovered that most have random diurnal patterns (Figures 3b, 3e and 3j) with the exception of June 1995 (Figure 3g), having six days of missing data but showed little of such character and that of June 1997 (Figure 3m), which had the normal pattern similar to Figure 1a. The averaged irregular patterns of the month of June caused the unexpected very low radiation outcome in Figure 2c. Thus, most times, the diurnal pattern of the radiation is irregular in the month of June. Then, the sun-earth distance is the longest and the experience of a long day and short night is prevalent while the sun is overhead, especially on June 21. Though the erratic diurnal DLR pattern has not been consistently observed in the month of June, it could occur in other months around June and last for about three months. In 1993, the pattern occurred only in June (Figure 3b) and July (Figure 3c) but was not observed in the month of May (Figure 3a). Whereas, in 1994, it was predominately observed from May to July (Figures 3d – 3f). However, in 1995, the irregular pattern could not be investigated for May due to non-availability of data, and though the pattern did not occur in June (Figure 3g), but it occurred in July (Figure 3h). In 1996, the irregular pattern occurred from May to July (Figures 3i – 3k). Throughout May (Figure 3l) and June (Figure 3m) of 1997, the pattern did not occur, though July (Figure 3o) showed some little resemblance of the erratic pattern.

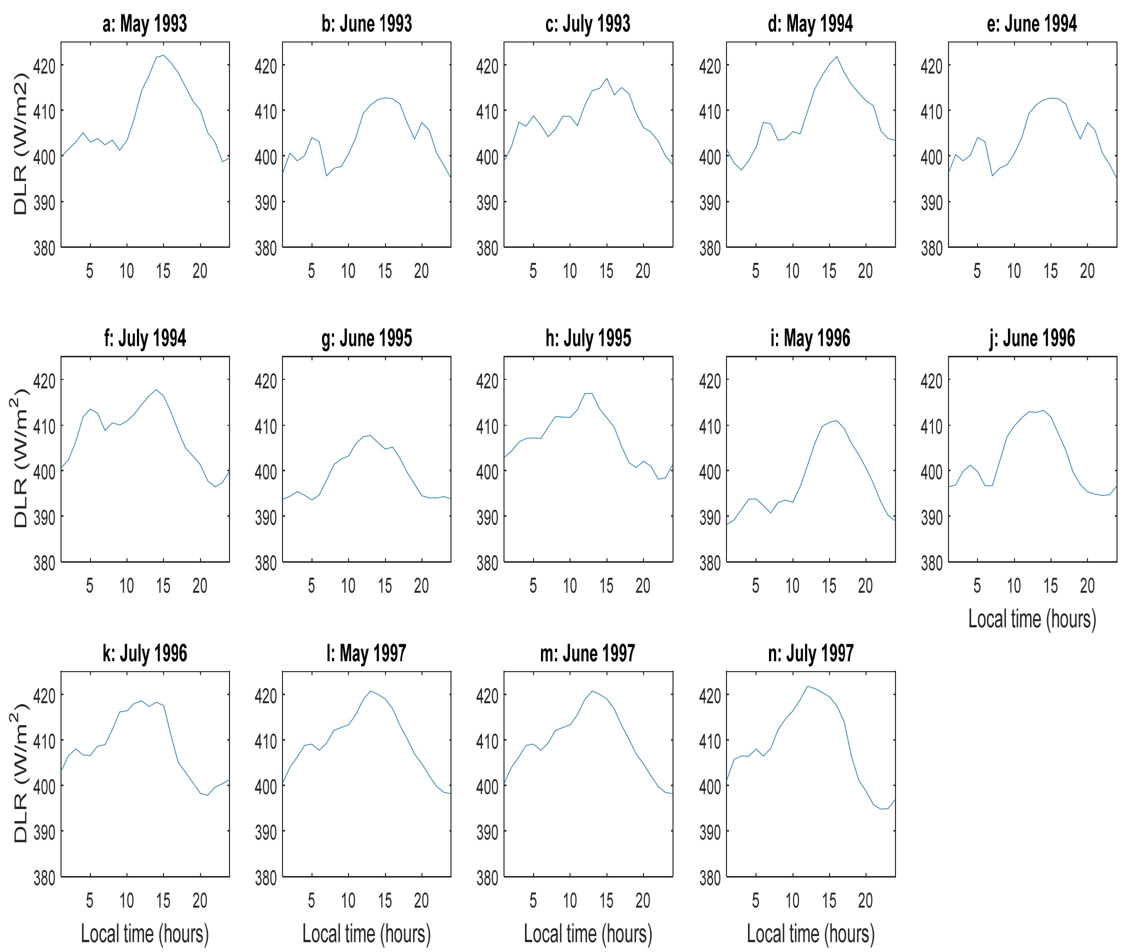

Figure 3. Monthly diurnal patterns of DLR around the mid of year period.

For the December diurnal pattern, except in 1993, which had a different graphical output somewhat similar to that of the March equinox of Figure 2b, December of 1992 (Figure 4b), 1995 (Figure 4h), 1996 (Figure 4k), and 1997 (Figure 4n) show the typical pattern of Figure 2e; that is, rising to a peak value and then decreasing before rising to a second peak value and finally returning to a minimum. Except in 1994 when there was no data, the double peak diurnal DRL pattern that dominates at the end of the year was found to always occur in diverse magnitudes lasting various durations. Just like the case of the established June pattern, it also persists for two to three months. For instance, in the case of 1992, notably from November to December (Figures 4a – 4b), the diurnal curves displaced about three peaks. The pattern was not seen in January of 1993 (Figure 4c) but occurred in November of the same year (Figure 4d), and then, was not noticed in December 1993, (Figure 4e), January 1994, (Figure 4f) and November 1995, (Figure 4g), it then occurred in December 1995 (Figure 4h) and lasted to January 1996 (Figure 4i). In 1997, the end of the year diurnal pattern of DLR occurred in November and December (Figures 4m – 4n). It did not occur in January 1998 (Figure 4o). If the patterns established for the diurnal variation of DLR both at the mid and the end of the year had occurred in the rainy and dry seasons, then it would have been seasonal effects. However, the periods the patterns did not occur as expected could be due to normal variation embedded in climatic parameters. It should be pointed out that some of these observations on the diurnal patterns of DLR were previously not discovered probably due to the meagre data (Udo, 2004; Obot and Chendo, 2014; Obot, 2015).

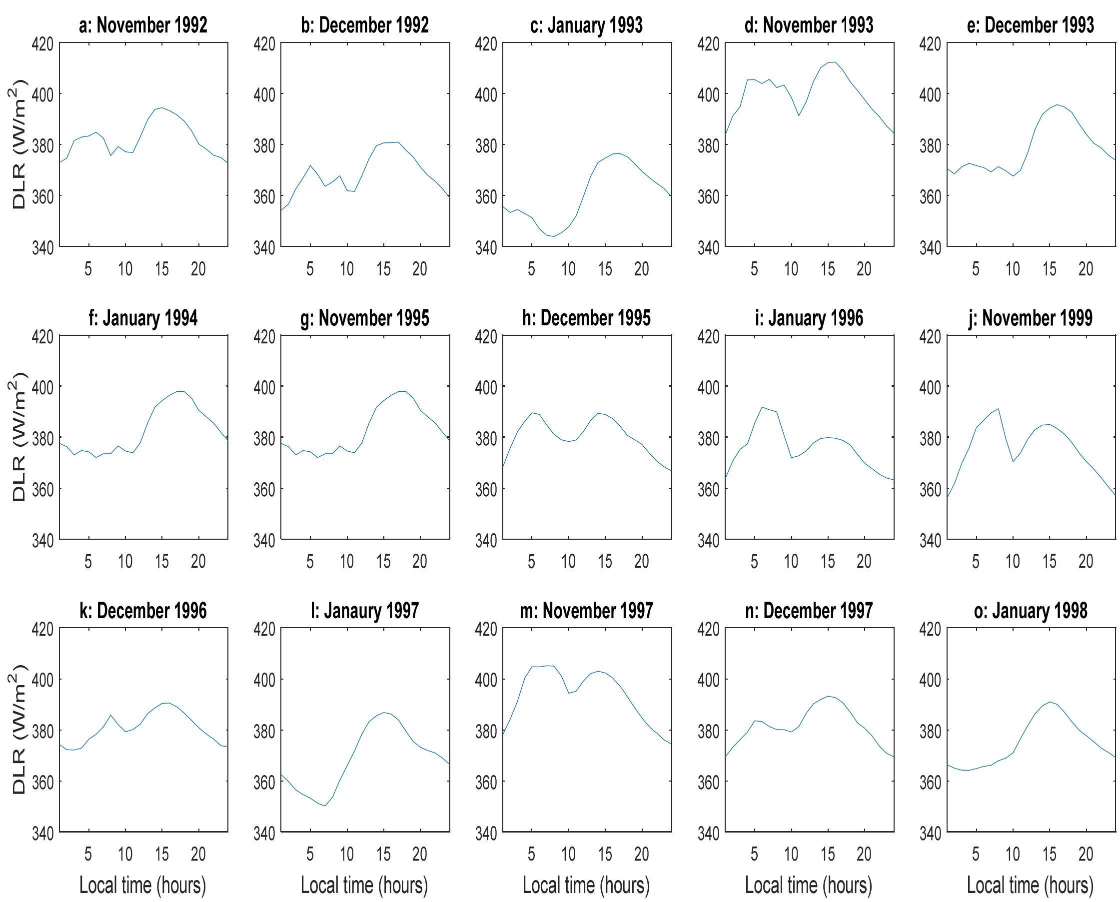

Figure 4. Monthly diurnal patterns of DLR around the end of year period.

3.2. DLR relationships with temperature and relative humidity

Based on available data, the concurrent diurnal and seasonal analyses of DLR, relative humidity (RH) and temperature can be considered only for 1996 and 1997. Different diurnal relationships exist between DLR and both of temperature and RH, which can be observed by comparing Figures 5a – d. During the early part of the day from 01:00 to 06:00 hours, the average diurnal DLR increases gradually from minimum (with slight fluctuations) through the 6th hour. Afterwards, it continues to increase but without fluctuating through the hours of 10 to when it peaks (Figures 5a and c). At the same early period of 01:00 to 06:00 hours, RH increases from 87% at the 1st hour to its peak of 95% at the 6th hour (Figure 5a). Whereas, the temperature decreases gradually from 18^{o}C to 22^{o}C during the early hours (Figure 5b). Another significant period is from 6:01 to 17:00 hours, where the peak of DLR occurs at 14:00 hour before going on a downward path, the RH reduced to a minimum in a reserved path and the temperature increased to the peak at 16:00 hour. During the last period of the day, from 17:01 to 24: 59 hours, while both DLR and temperature decrease gradually to the lowest values at midnight, RH is steadily rising.

Similar to the diurnal relationships also, there are seasonal trends relating DLR to temperature and RH, which can be observed from Figures 6a – d. However, DLR in June 1996 takes unusual dive which is not the case in 1997 and previous studies (Miskolczi et al., 1997; Udo and Aro, 1999). Even though the deviation is significant, such is not unexpected due to observed variations noticed in the monthly diurnal DLR patterns. The radiation is mostly low during the dry season but high in the rainy season. However, the temperature has an inverse seasonal trend with DLR. Irrespectively of slight differences in the seasonal patterns in 1996 and 1997, noticeably RH and DLR have similar patterns if the usual midyear seasonal DLR pattern in 1996 is ignored. In Ilorin, the direct seasonal patterns between DLR and RH indicates the dependence of the radiation more on water vapour than temperature.

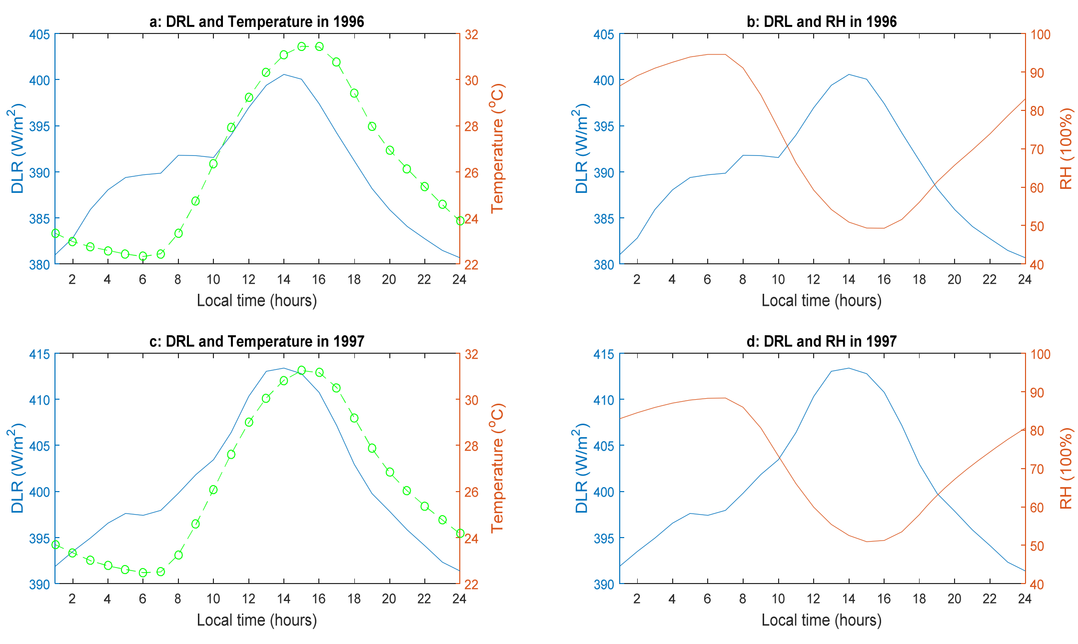

Figure 5. Diurnal variations of DLR with (a) Temperature in 1996, (b) RH in 1996, (c) Temperature in 1997, and (d) RH in 1997, at Ilorin.

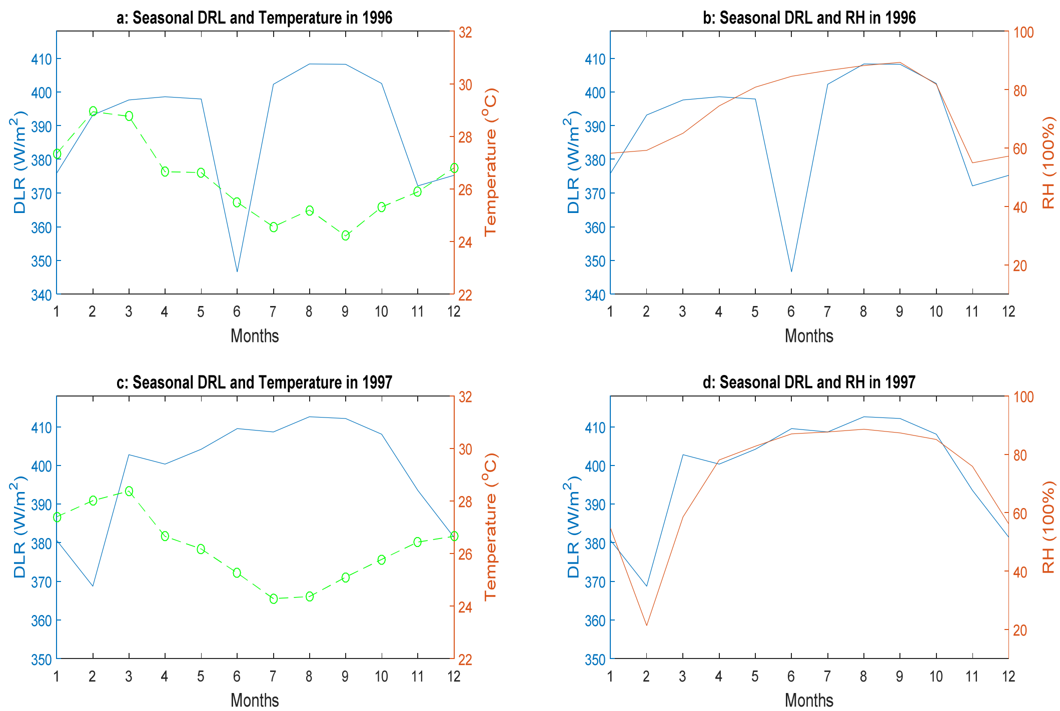

Figure 6. Seasonal relationships between DLR with (a) temperature in 1996, (b) RH in 1996, (c) temperature in 1997, and (d) RH in 1997, at Ilorin.

3.3. Monthly variation of DLR

The MAD statistic can be used as an indicator of the extent of variation in DLR. It can be observed from Table 1 that the values of MAD are mostly high between the end and early months of consecutive years (say roughly from Octobers to Februarys). Even when the monthly mean values of the radiation are low during this period compared to the rainy season months (Figure 6a and 6b); however, based on monthly error term, the higher the radiation, the less it varies. The MAD values arbitrarily considered as high are from 10.0 upwards, which are mainly for the dry season, while the low values are mostly found during the high rainy months between Julys and Septembers. However, if by choice, a critical value of 12.0 is set for MAD, then those months with values of MAD ≥ 12.0 are probably the months of the Harmattan season. Based on that assumption, from Table 1, the Harmattan season is from November to January and rarely extends to February. Throughout the 5½ years data considered in this study, the Harmattan occurred mostly in both of December and January whereas it was rare in February.

Table 1. The monthly median absolute deviation (MAD) values of DLR at Ilorin, Nigeria, where the threshold of MAD ≥ 12.00 was arbitrarily taken to indicate the Harmattan period.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1992	-	-	-	-	-	-	-	-	8.27	10.10	15.44	13.66
1993	11.32	18.8	10.38	8.55	9.52	9.78	8.44	8.12	9.88	10.28	11.79	13.58
1994	20.41	9.66	9.73	8.55	8.44	8.62	7.37	7.09	-	-	-	-
1995	-	-	-	-	-	-	6.73	5.23	7.58	7.59	17.64	16.10
1996	14.58	10.06	9.25	8.06	7.85	7.77	7.54	6.69	6.69	9.70	7.58	10.76
1997	13.85	9.11	7.08	9.01	8.77	8.67	7.41	6.31	7.73	7.47	11.96	15.02
1998	14.39	10.70	-	-	-	-	-	-	-	-	-	-

4. Discussion

Apart from longwave radiation of the sun's spectrum that comes directly to the surface of the earth through the atmospheric window, also the radiation is occasionally absorbed and reemitted by some atmospheric gases. Additionally, rays of total solar fluxes while passing through the atmosphere (or medium) is transformed to (longer wavelength) longwave radiation (Obot et al., 2018; Wild et al., 2013; Igbal, 1983). To an extent, the surface radiation budget depends on the available radiation at the surface of the earth. Since DLR can be obtained from the transformation of total solar radiation and also received directly from the sun's spectrum, hence during the daytime DLR is high. As the sun rises, the gain between received and transmitted radiation increases. The intensity of DLR around the ground is high probably while the sun is directly over the location. When the intensity of the radiation is high, there is the corresponding warming at the ground, which is transported to the atmosphere by convection and eventually further translates to high atmospheric temperature.

Furthermore, the high temperature of the atmosphere during the daytime could also be due to the activities of radiative transmittance of absorbed total solar radiation by atmospheric gasses. There could be some time lag between maximum temperature and highest intensity of DLR. Thus, the sun is most likely overhead in Ilorin at around 14:00 hour local time because it is the period of the highest radiant thermal energy of the day (Figures 1a-c, 2a-c). Besides, around 6:00 hours, the upturn in diurnal temperature could indicate the period when environmental moist dries up, and the atmosphere warms considerably as the sun begins to shine.

Expectedly, during the dry season, the seasonal temperature is high due to the hot, dry air that brings the dry season in this region. Seemingly, highest seasonal temperature occurs immediately after the Harmattan period in the dry season (Figures 6a and c). For instance, Table 2 indicates that the Harmattan occurred in January but not February of 1996. However, the hottest month was instead February in Figure 6a. Possibly the deeming of the atmospheric aerosol produces atmospheric heat that balances the low temperature recorded during the previous month in the dry season. The noticed gap in the occurrence of Harmattan between consecutive months (consider November 1992 to February 1994 on Table 1) could be due to the irregular frequency of the concentration of atmospheric dust from time to time (Goudie and Middleton, 1992).

As earlier mentioned, the sun-earth distance could be responsible for those patterns of extreme differing scenarios around the respective months of June and December. The low average values around the June solstices (Figure 2c) are probably due to the sun being the farthest away from the earth; therefore, even if there is much water vapour in the atmosphere because of the rainy season, the incoming primary radiant energy is slightly low. Moreover, the erratic nature of the diurnal DLR around midyear (Figures 3b–3f) could be attributed to the changes in atmospheric constituents in the midst of low intensity of radiant energy from the sun.

For the end of the year scenario, the DRL loss during the day between the hours of 7:00 and 12:00 where it typically increases, could be attributed to the intertwining effect of the earth's geomagnetic field and cosmic rays from the sun that are felt mostly when the distance between the sun and the earth is shortest. That is because the sun is the primary source of radiation and its influence on the earth's climatic system is well recognized (Beer et al., 2000; Kesseler and Jaeger, 2003), especially the effects of the semiannual periodicity (Priester and Cattani, 1962; Harris and Priester, 1962). The phenomenal departure of DLR diurnal patterns from normal during the mid and end of the year periods is not peculiar to this region alone as Hoch et al. (2007) found others to occur in the polar region.

The seasonal pattern of DLR is similar to its diurnal pattern, which is a major deviation from those of RH and temperature. The difficulty in understanding the linked mechanisms between DLR and influential factors like water vapour (Allan, 2006) is likely due to changes from diurnal to seasonal patterns of such factors. According to Equation (2), which relates relative humidity (RH%) to water vapour pressure and saturated vapour pressure, when RH increases, then there should be a corresponding increase in water vapour pressure if saturated vapour pressure is constant. Since RH exhibits different diurnal and season patterns, probably water vapour pressure may behave differently.

$$RH\ \% = \frac{water\ vapour\ pressure}{saturated\ vapour\ pressure} \times 100 \quad (2)$$

If the differing patterns at around the end and mid of the year were not consistent throughout, then it should be caused by an irregularity or varying occurrence that is pronounced occasionally. Though still somewhat related to the changing position of the sun, the two scenarios of diurnal DLR at the mid and end of the year could be the aftermath of season change from one to another (Babatunde et al., 2009). Ilorin is located around the region where the inter-tropical discontinuity (ITD) migration influences its seasons: when the ITD position shifts to the North at 10^o and 12^{o}N around the months of March and April, the station experiences a mixture of two winds of dusty wind of the dry season and the cool wind of the rainy season. By May and June when the dusty wind no longer exists in the region except the cold wind of the rainy season, then we find the erratic diurnal pattern of DLR occurring. Besides, during the months of November and December, the dry season wind is totally prevalent and all traces of the cold wind that accompanied the rainy season have been totally eliminated; at this period the two peaks DLR pattern occurs.

Coincidentally, the monthly periods of high variation in DLR as depicted by the MAD fall within the Harmattan season, which is a subset of the dry season of high dust and misty atmosphere and the period is usually characterised by low RH (Seefeldt et al., 2012). The occurrence of high variability in DLR overlapping with low RH is probably due to the effect of the dust, and as such, the level of variation of the radiation can be used to deduce the Harmattan months. It is likely that the aerosols in this region block and absorb the radiation for a while before reradiating it back into the atmosphere, which accounts for the high variation during the Harmattan period. It has been construed in previous studies that even though there are other contributing factors like cooler air and fewer clouds, the low DLR during the dry season results from heavy dust particles in the atmosphere (Miskolczi et al., 1997; Dufresne et al., 2002). On the contrary, a paltry increment of about 1 W/m^2 as a contribution from aerosols to DLR occurs in the Arctic and Antarctic regions (Morcrette, 2002). Therefore, aerosols also serve as emitters of DLR just like the greenhouse gases and increase DLR (Ramanathan et al., 2001). It is possible for the dust particles in the equatorial region to behave like the aerosols of the Polar Regions even if their natures are different. As suggested by Obot et al. (2018), the prevalent low DLR during the dry season could be outrightly due to the low water vapour content of the atmosphere rather than the presence of the dust particles as evidenced by Figure 6a (except during the mid-year). In West Africa, where Ilorin is situated, mineral dust at the surface of the earth may reduce DLR during some hours of the day in a given month (Mallet et al., 2009). However, the overall effect is that dust increases DLR at the end, though others radiations like shortwave solar and net longwave are reduced (Zhao et al., 2011; Babatunde et al., 2009).

As earlier mentioned that the radiation has a seasonal character (Miskolczi et al., 1997; Udo and Aro, 1999) and the present work has confirmed the seasonality with another data set for the same location. It appears that the peaks of diurnal DLR and temperature do have varying matching patterns all over the globe. Marty et al. (2002) showed that the peak of diurnal temperature occurred a little earlier than that of DLR at the Polar Region. However, in this region, such analysis reveals that the reserve is the case as the peak of DLR precedes that of temperature. The difference could be due to the varying atmospheric composition between the two regions, take for instance the fact that water vapour (the major gas that influences DLR) is high at the equatorial region but low at the Poles.

5. Conclusion

The diurnal pattern of DLR at Ilorin, Nigeria during the mid of the year is irregular, while it is a two-peak pattern around the end of the year and both are distinctively different from the average diurnal pattern. The sun-earth

relationship is likely responsible for the peculiar patterns both around the midyear and year-end periods, though the adjustment of the atmosphere at Ilorin to the migration of ITD that brings about changes in the season could also be responsible for the effects. The sun-earth distance is longest in June and shortest in December. During the months of low RH, which fall into the Harmattan season from November to January, the radiation is highly variable probably due to the high aerosols content of the atmosphere. Even though it is known that DLR is high during the rainy season, it may not always be true.
Moreover, based on the severity of the variation of the radiation, the Harmattan season can be detected and it was found that the highest seasonal temperature occurs after the Harmattan period. Hence aerosols in the atmosphere induce high variability in DLR rather than 'delete' it. The diurnal relationships between DLR and both of temperature and relative humidity in Ilorin, Nigeria were observed to be interlocking.

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