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Rain Height and Surface Temperature Variations for Nigeria

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Abstract There is paucity of data on direct attenuation measurement in the tropics due to rainfall along the earth-space links. Most of the studies reported in the literature have been carried out in temperate regions where solid precipitation is common; therefore there is need to supplement the meagre data available in the tropical regions. It is also well-known that most of the microwave signal attenuation occurs above the 10 GHz (X-band). Rain height data were obtained from the Tropical Rainfall Measuring Mission (TRMM) 3B43 V6 satellite while those of the surface temperature data were sourced from AIRS satellite for 37 stations in Nigeria as reported in the literature. Additional data used in this study include the monthly temperature measurements as also reported in the literature. Subsequently, these data have been analyzed to establish the statistical correlation between the 0^0C isotherm heights and the surface temperature for 0.01% of the time. Results of the rain height and temperature variations presented in this letter suggest latitude dependence rather than variations based on longitudinal positions of the stations. More so, the analyzed results have shown that the southern region experience rainy season a month and two months earlier than the middle-belt and northern regions respectively. Additionally, the study presents empirical relationship between rain height and surface temperature, which may be useful in the estimation of slant path attenuation for design of satellite communication equipment and link budget analysis.
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Index Terms— Harmattan, Rain height, Rainfall rate, Stratiform, Surface temperature, 0^0C isotherm, TRMM, Tropical region.

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1 Introduction

Rain height is generally known to be highly correlated with signal attenuation and co-channel interference due to scattering. The rain height distribution is important because it can be used to investigate the mechanisms responsible for variations in the attenuation distributions at any station. The non-uniformity of rainfall in both the horizontal and vertical directions makes the estimation of slant-path attenuation rather complex. At frequencies above 10 GHz, the effects of attenuation induced by rain are quite significant. The result of these is evident in satellite-earth microwave signal amplitude's fading, scintillations, depolarization, and receiver antenna noise. The prediction methods being used to estimate the degree of signal attenuation encompasses the various location-specific meteorological factors; and rain height is one such factor. The rain height, H_R is also directly related to the zero degree isotherm height, H_0.

Furthermore, this study presents empirical relationship between rain height and surface temperature. This is necessary because apart from increased temperature sometimes experienced by satellite antennas, temperature is also one of the factors on which the ITU-R specific attenuation ($\gamma = k R^{\alpha}$) parameters, k and α depends (in addition to frequency, polarization and elevation).

One major source of slant-path attenuation prediction errors is the complex nature of the rainfall structure along this path [1]. The difficulties in relating H_R to H_0 in the tropics had also been attributed to insufficient database and peculiar rainfall types existing in the tropical regions [1]. The rain height is being employed in ITU-R Rec. P.618-10 [2] (for slant-path attenuation prediction), ITU-R Rec. P.452-14 [3] (for co-channel interference estimation), ITU-R Rec. P.620-6 [4] (for coordination distances), and ITU-R Radio Regulations Appendix 7 [5] (for regulatory issues of coordination) [6]. The ITU-R Rec. P.618-10 uses the rain height as the boundary below which the slant-path attenuation is integrated while the ITU-R Rec. P.452-10 uses it to discriminate rain scatter from ice scatter, incorporating variability into the mean freezing height. According to [6], the rain height can be considered to represent the boundary between the rain region and the snow region and it often correspond to the 0^0C isotherm (mostly during stratiform rain events). In the vertical dimension, the rainfall rate is assumed to be constant up to the point that represents the top of the rain height and attenuation beyond the height is considered insignificant, and thus neglected [6]. The difference between the effective rain height and the freezing height is taken to be 360 meters according to ITU-R Rec. P. 839-3 [7], and is expressed as:

$$H_R = 0.36 + H_0 \quad km \tag{1}$$

Where H_R represents the mean rain height above mean sea level and H_0 is the mean 0^0 C isotherm height above mean sea level.

Nigeria is a tropical region that lies between the geographical area of 4°N, 3°E and 14°N, 15°E in the South-Eastern edge of the West African region. It is characterised by rainy and dry seasons. The rainy season (between the months of April and October) is heavily influenced by an air mass originating from the South Atlantic Ocean, known as the South-West (monsoon) wind or the Tropical Maritime (mT) air mass, while the dry season (between November and March) is accompanied by a dust laden air mass from the Sahara desert, known as Harmattan or the Tropical Continental (cT) air mass [8]. Harmattan (between December and February) is the dry, hot-by-day and cold-by-night dust-laden North-East wind, which is usually associated with the variable intensification of the sub-tropical anticyclone [9]. Nigeria, like any other tropical region is characterized mostly by convective rainfall types (Convective, Monsoon Precipitation and Tropical Storm).

2 Methodology

Rain height data for 37 stations for 0.01% of the time, in Nigeria were sourced from [10]. Furthermore, monthly temperature data for 18 stations in Nigeria was extracted from the work of [8].

In convective rainstorms (R >10 mm/h), the effective rain height, H_R depends on the rain rate because strong storms push rain higher into the atmosphere, and thereby lengthening the slant-path [11].

According to [12], to determine the slant path attenuation, a modified value of effective path length must be used: -

$$A = \gamma \frac{1-\exp\left[-\alpha\, b \ln\left(\frac{R_{\%p}}{10}\right)\right] L_S \cos\theta}{\alpha\, b \ln\left(\frac{R_{\%p}}{10}\right)\cos\theta}\;;\; R_{\%p} > 10\text{mm/h} \qquad (2)$$

Where the empirical constant $b = 1/22$ and $\gamma = k R^{\alpha}_{\%p}\ (dB/km)$.

And based on measurement data, the derived empirical expression for effective rain height H_R was obtained as:

$$H_R = \begin{cases} H_0\ ;\ R \le 10\,mm/h \\ H_0 + \log\left(\frac{R}{10}\right);R > 10\,mm/h \end{cases} \qquad (3)$$

H_R (km) is the rain height, L_S (km) is the slant path up to rain height, H_0 (km) is the 0^0C isotherm height above mean sea level and its value can be obtained from the isotherm chats of the Recommendation ITU-R P.839-3.

3 Results and Discussions

The 0^0C isotherm height and surface temperature regression relationship obtained from the correlation plot of Figure 1 is a linear-fitting function; and it is expressed as:

$$H_0 = 4.265 + 0.005 * T_S \quad km \qquad (4)$$

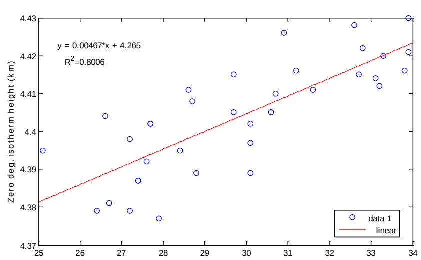
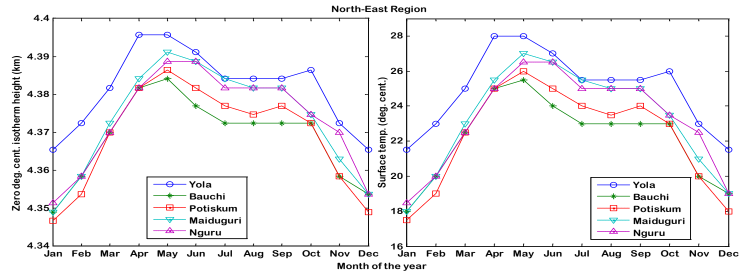


Fig. 1 Fitting plot for 0^0C isotherm height and surface temperature.

Combining equations (3) and (4) yields

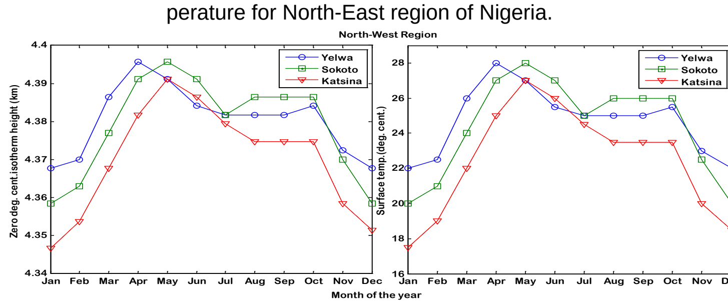
$$H_0 = 4.265 + 0.005 * T_S + \log\left(\frac{R}{10}\right);\ R > 10\,mm/h \quad km \qquad 95)$$

Where T_S is the surface temperature; and R is point rainfall rate for 0.01% of the time.



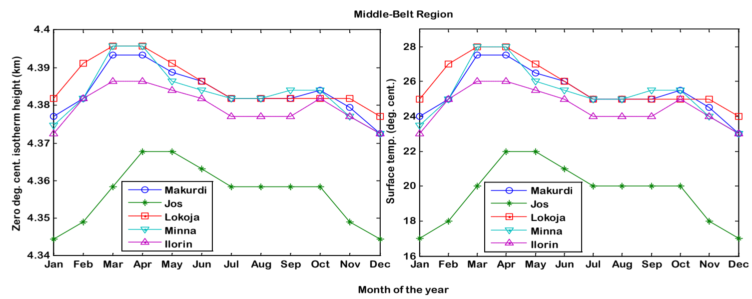
(a) (b)

Fig. 2 Monthly variations of (a) 0^0C isotherm height and (b) Surface temperature for North-East region of Nigeria.



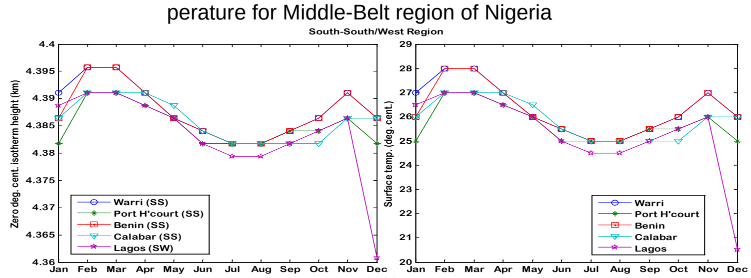
(a) (b)

Fig. 3 Monthly variations of (a) 0^0C isotherm height and (b) Surface temperature for North-West region of Nigeria.



(a) (b)

Fig. 4 Monthly variations of (a) 0^0C isotherm height and (b) Surface temperature for Middle-Belt region of Nigeria



(a) (b)

Fig. 5 Monthly variations of (a) 0^0C isotherm height and (b) Surface temperature for South-South/West regions of Nigeria.

The Northern (North-East and North-West) region of the country (Figures 2 and 3) experience the highest temperature and 0^0C isotherm heights (and thus rain heights, H_R) between the months of April to May and September to October of the year. These values also correspond to the beginning and end of the rainy season respectively. The implication of this is that the rain heights are pushed further upwards during the rainy seasons; thus lengthening the slant-path and consequently, increasing the attenuation due to rainfall. Indeed, this is as a result of the fact that Nigeria, like any other tropical region is characterized mostly by convective rainfall types (see equations (2) and (3)). Furthermore, the lowest rain heights, H_R and temperature are observed in the months of December to January and July to August. This corresponds to the Harmattan period and the end of the rainy season respectively. The dry season was observed to be characterized by very low rain height and temperature (around December-January) in the region.

The Middle-Belt region (Figure 4) experience highest rain heights, H_R and temperature between March and April, and September and October, which correspond to the rainy season of the year. The rainy season commence a month earlier when compared to the northern region of the country. This could be attributed to the fact that the rainy season is brought about by the south-west monsoon wind from the South Atlantic Ocean. The effect is experienced earlier in the southern and middle-belt regions respectively in contrast to the northern regions. Again, the rainy season seem to last a month longer (September) than the northern regions (August). The months with the lowest values of H_0 and temperature (dry season) was observed around December and January. However, Jos exhibited the lowest values of rain height and temperature in the region.

The South-South region show highest rain heights and temperature between the months of February to March and October to November (Figure 5). This coincides with the end of the dry season, on one hand, and the end of the rainy season on the other hand. In addition, the region experience rainy season one and two months earlier when compared to the middle-belt and northern regions, respectively. This can be explained by the proximity of the region to the South Atlantic Ocean. Secondly, lowest rain heights (and temperature) were observed between July-August and December-January, coinciding with the commencement of the rainy season and Harmattan period, respectively. Observations show that similar effect was experienced in the north-east and north-west regions.

The South-western region, represented by Lagos, exhibited similar characteristics with the south-south region. It however, was observed to show much lower rain heights and surface temperature compared to the south-south regions, particularly at the end of the rainy season (or at the commencement of Harmattan). This is seen in the sharp drop in rain height (and temperature) in the month of December as shown in Figure 5.

4 Conclusions

The month-to-month variation relationship between the 0^0 C isotherm height, H_0 and surface temperature is presented. The rain height and temperature variation seems to suggest latitude dependence rather than variations based on longitudinal positions of the stations. The southern regions experience rainy season a month and two months earlier (February-March) than the middle-belt and northern regions. To sum up, the rainy season begins around February-March in the southern region and April-May in the north, while the dry season begins around December and January for both northern and southern regions.

Again, the study present empirical relationship between rain height and surface temperature, useful in the estimation of slant path attenuation for satellite communication equipment design and link budget analysis.

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