

Research Article

Rain Height Statistics Based on 0°C Isotherm Height Using TRMM Precipitation Data for Earth-Space Satellite Links in Nigeria

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In the prediction of attenuation due to precipitation related phenomena, the 0°C isotherm height plays a vital role. In this paper, 2 years of precipitation data obtained from the Tropical Rain Measuring Mission (TRMM) satellite had been analyzed to establish the distribution of rain height based on 0°C isotherm heights over six locations in Nigeria. Probability of exceedance of rain heights in each of the locations was compared between the two seasons in Nigeria. Rain heights distribution was also compared with the ITU-R P.839 recommendation. The overall results show seasonal, rainfall type's dependence and overestimation of the rain height predicted by the ITU for Nigeria.

1. Introduction

As the satellite communication link continues to expand its bandwidths for higher data rates, among others, system performances can be marred by the increased propagation challenges at these higher frequency ranges. Rain induced attenuation of microwaves poses a serious challenge to system/signal availability at frequencies above 10 GHz. For good system design, the designer must provide adequate fade margins to ensure system availability. There are a number of propagation mechanisms affecting Earth-space satellite communications that are a major concern in the system design. These include gaseous attenuation, cloud and fog attenuation, and rain and ice attenuation [1, 2]. However, rain-induced attenuation has been identified to cause the most serious degradation to system performances of both terrestrial and satellite links operating at frequencies above 10 GHz [3–5]. In order to estimate the level of the degradation, most researchers normally used prediction methods when actual measurements are not available. Among the meteorological parameters needed for prediction method is the annual average of the 0°C isotherm height. This 0°C isotherm height is the height in the stratiform type of rain where the frozen hydrometeors begin to change state into

liquid rain due to temperature difference [3, 6]. The ITU-R [7] gave a global map of 0°C isotherm height above mean sea level (km) on a resolution of 1.5° by 1.5° in both latitude and longitude to be used in regions of the world where no location specific information is available. However, study revealed that this height strongly depends on local weather [8, 9].

In this paper, the annual average, year-to-year variability, probability distribution levels, and seasonal variation of 0°C isotherm height derived from TRMM-PR data for some locations in Nigeria are presented.

2. Climatology of Nigeria and Source of Data

Nigeria lies between latitudes 4° and 14°N and longitudes 2° and 15°E with a varied landscape and climate. The country is in the western part of Africa. The seasonal northward and southward oscillatory movement of the intertropical discontinuity (ITD) largely dictates the weather pattern of Nigeria. The moist southwesterly winds from the South Atlantic Ocean, which is the source of moisture needed for rainfall and thunderstorms to occur, prevail over the country during the rainy season (April–October). In reverse, northeasterly winds which raise and transport dust particles from the Sahara Desert prevail all over the country during

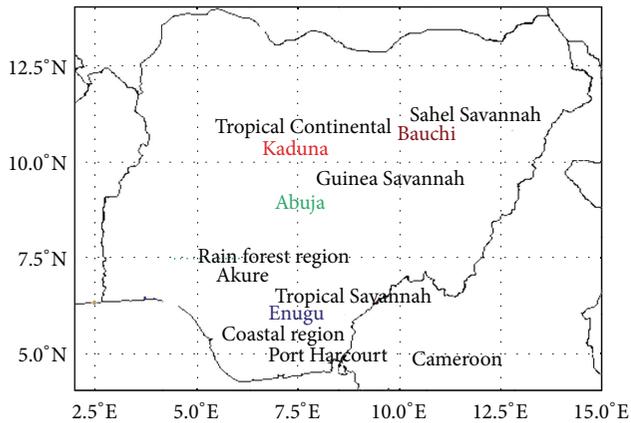


FIGURE 1: Map of Nigeria showing the characteristics of the observation sites.

the dry/Harmattan period (November–March). The overall changes in temperature, rainfall, and other meteorological parameters determine the changes in climate in the country each year. Nigeria being a tropical country experiences abundant sunshine all through the year.

The 0°C isotherm height is derived from TRMM-PR observations taken over some locations in Nigeria: Abuja, Akure, Bauchi, Enugu, Kaduna, and Port Harcourt which are located in 344, 358, 800, 223, 645, and 80 m above sea level, respectively. Figure 1 presents a map showing the characteristics of the sites while Figure 2 shows the local weather observed in each of the locations during the period of study. Each of the locations has been chosen to represent the different climatic region of Nigeria (Figure 1). The TRMM-PR is the first space borne rain radar and the only instrument on TRMM that can directly observe vertical distributions of rain. The satellite was launched in November 1997 with an altitude of 350 km and frequency of 13.8 GHz. Although the design lifetime of the satellite was 3 years, the radar still remains in good condition and continues to send high-quality data but presently at a higher altitude [3]. Further details of the radar are available in the works of Thurai et al. [3], Awaka et al. [10], and Iguchi et al. [11]. Event classification in TRMM radar data is assigned with a routine algorithm, namely, 2A23. The algorithm identifies each of measured profile data based on vertical and horizontal distribution of radar reflectivity factor. They are classified as stratiform, convective, or other precipitation on a 4.3 km by 4.3 km pixel basis. The bright-band height is obtained from the peak value of the algorithm outputs at the point when the bright band is detected.

Two years (January 2010 to December 2011) of TRMM PR 2A23 data had been processed to obtain the bright-band heights. The algorithm is tested whether a bright band exists in rain echoes and determines the bright-band height when it exists [3, 10, 12]. It also detects isolated warm rain whose height is below the 0°C height. Averaging of the data on a grid basis was not performed in areas where there is no PR data as well as areas where all grid points with bright band-heights are less than 2 km. This is because some of the range gates below 2 km are considered to have significant clutter

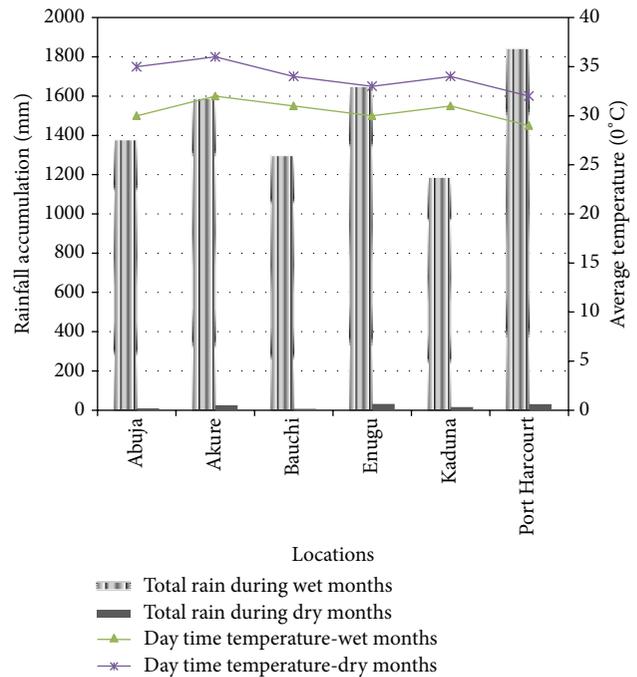


FIGURE 2: Local weather observed during the period of study.

contamination and the radar reflectivity is assumed to be constant below this height. Hence, the algorithm could not identify the event as stratiform precipitation as pointed out in the work of Thurai et al., [3]. The bright-band height almost lies below the 0°C isotherm height.

The 0°C isotherm height or freezing height level height is recommended by the ITU-R, in particular ITU-R [13] for calculating rain-induced attenuation statistics meant for planning and design of Earth-space telecommunication systems.

3. Distribution of 0°C Isotherm Heights over Some Stations in Nigeria

Figure 3 presents the annual distribution of monthly average 0°C isotherm heights over the six locations considered as well as the value recommended by the ITU-R. It could be observed that 0°C isotherm heights are higher during the wet months of the year (April–October) than the rest of the calendar months (dry months—November–March). This is in agreement with the observation made by [9] that during the period of enhanced shower activities, 0°C isotherm heights are higher than during the dry months. In overall, 0°C isotherm heights vary from 4.160 to 4.457 km, 4.109 to 4.458 km, 4.170 to 4.460 km, 4.146 to 4.451 km, 4.162 to 4.455 km and 4.117 to 4.462 km over Abuja, Akure, Bauchi, Enugu, Kaduna and PortHarcourt respectively. However, ITU-R [7] predicted an annual average value of 4.86 km for this region with an average percentage difference of about 4% of the measured values. The implication is that rain attenuation estimated using the value predicted by the ITU will be overestimated in this region due to the annual average estimated value of the 0°C isotherm height used.

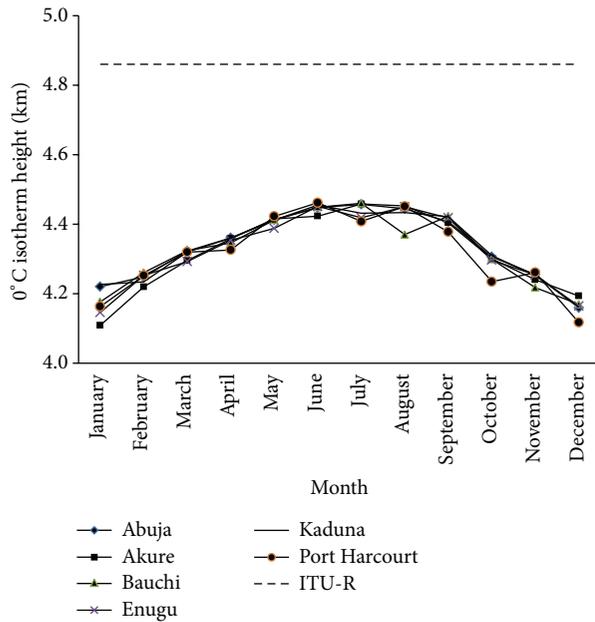


FIGURE 3: Average monthly variation of the 0°C isotherm height.

Figure 4 shows the year-to-year variation of 0°C isotherm height for the period of study as well as overall average as a function of location of study. The difference is noticeable in the 2010 case, which shows higher values when compared with 2011. For example, in 2010, the mean values of 0°C isotherm height are found to be 4.744, 4.743, 4.737, 4.735, 4.732, and 4.722 km over Abuja, Kaduna, Bauchi, Port Harcourt, Akure, and Enugu, respectively, while in 2011, the values are 4.655, 4.650, 4.647, 4.645, 4.635, and 4.618 km over Akure, Abuja, Kaduna, Enugu, Bauchi, and Port Harcourt, respectively. Judging from these results, we observed variation in 0°C isotherm height at different location and in different year. For example, the percentage difference between 2010 and 2011 when compared with the mean height is 2, 1.6, 2.2, 1.6, 2, and 2.5% over Abuja, Akure, Bauchi, Enugu, Kaduna, and Port Harcourt, respectively. This may be due to the activities of the intertropical discontinuity over the locations. Further observation shows that Abuja with latitude 9.04°N recorded the highest value of 4.744 km while Enugu with latitude 6.24°N recorded the least value of 4.722 km. However, in 2011, Akure with latitude 7.18°N recorded the highest value of 4.655 km while Port Harcourt with latitude 4.43°N recorded the least value of 4.618 km. These results do not depend very much on latitude of the stations as earlier observed by [8].

Figures 5(a), 5(b), 5(c), 5(d), 5(e), and 5(f) show the averaged distribution of 0°C isotherm height for the two seasons in Nigeria as well as the average years. As earlier stated, the two seasons considered are wet/rainy season (April–October) and dry season (November–February of the following year) for all stations. Generally, the variation shows the expected seasonal trend of a wet season showing the higher rain heights and the dry months showing the lowest rain heights. For example, Figure 5(a) presents the result of 0°C isotherm height over Abuja, Nigeria. It could be observed that, during the wet months, the heights vary between 3.48 and 4.85 km

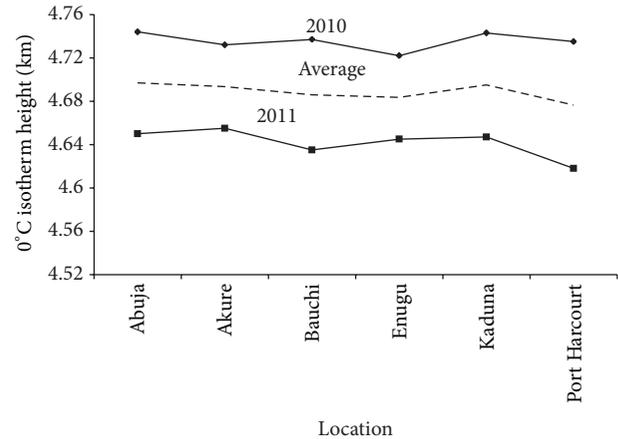


FIGURE 4: Year-to-year variability of 0°C isotherm height over all the stations.

over probability range 0.01–99.99% of time the 0°C isotherm height is exceeded, while, during the dry months, the heights vary between 3 and 4.76 km over probability range 0.01–99.99% of the time the ordinate is exceeded. The same trend could be observed in other locations (Figures 5(b), 5(c), 5(d), 5(e), and 5(f)) although with different variation in the 0°C isotherm heights values. This is imputable to the fact that Nigeria located in the tropical region has closely related climatic conditions and rainfall pattern throughout the country. The variation of ground temperature over Abuja, Akure, Bauchi, Enugu, Kaduna, and Port Harcourt is $30\text{--}35^{\circ}\text{C}$, $32\text{--}36^{\circ}\text{C}$, $31\text{--}34^{\circ}\text{C}$, $30\text{--}23^{\circ}\text{C}$, $31\text{--}34^{\circ}\text{C}$, and $29\text{--}32^{\circ}\text{C}$, respectively, during wet and dry seasons. The total rainfall during the dry seasons over Abuja, Akure, Bauchi, Enugu, Kaduna, and Port Harcourt is 5.2 mm, 21.1 mm, 3.2 mm, 28 mm, 12.1 mm, and 26.85 mm, respectively, and the wet season is 1378.0 mm, 1588.5 mm, 1297.3 mm, 1649.2 mm, 1186.6 mm, and 1842.9 mm, respectively. It could be further observed that, for all the months, the heights vary from 3.21 to 4.81, 3.43 to 4.83, 3.49 to 4.7, 3.46 to 4.72, 3.62 to 4.94, and 3.55 to 4.64 over probability range 0.01–99.99% of time the ordinate is exceeded over Abuja, Akure, Bauchi, Enugu, Kaduna, and Port Harcourt, respectively.

It is worth mentioning here that the 0°C isotherm heights over Kaduna in different seasons are appreciable, but the variation of 0°C isotherm height over Abuja is insignificant at low probability levels. The appreciable values observed over Kaduna might be due to the nature of the rain in the region which is mostly of thunderstorm rain during the months of observation. It has been reported in the work of Ajayi and Barbaliscia [6] that, in the tropics, during the months when thunderstorm rain is more prevalent, 0°C isotherm heights during rainy conditions increased. The overall results show distinct seasonal dependence and no variation of latitudinal dependence is observed.

4. Conclusion

Two years of data from the TRMM-PR satellite had been employed to study the 0°C isotherm height over some

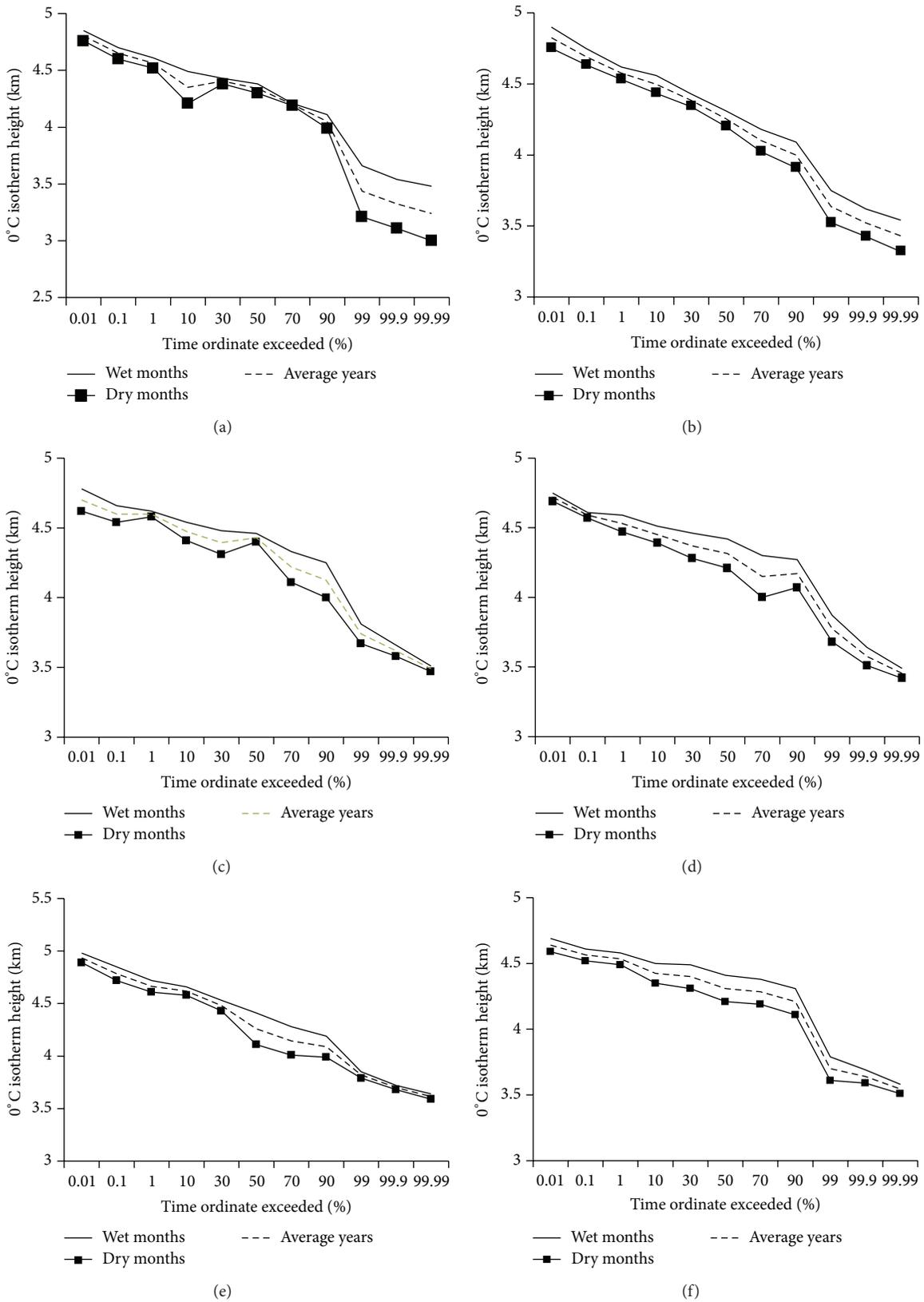


FIGURE 5: Distribution of 0°C isotherm heights during different seasons over (a) Abuja (b) Akure, (d) Enugu, (e) Kaduna, and (f) Port Harcourt.

selected locations in Nigeria and from the result, it could be observed that the 0°C isotherm height shows seasonal type dependence. Year-to-year variation shows slight differences with 2010 showing higher values than 2011. The result also shows that the 0°C isotherm height is location dependent with no two stations studied having the same value. Comparison with the predicted value by the ITU-R shows overestimation of about 4% as compared to the measured value over the stations. The result will be useful in estimating location dependent fade margins required for user availability of satellite and terrestrial line of sight communication links for this region.

Conflict of Interests

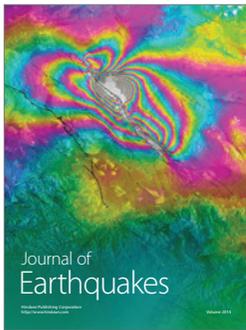
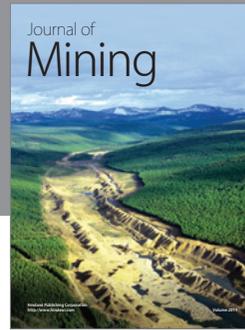
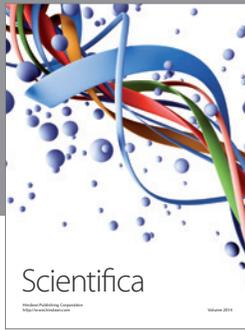
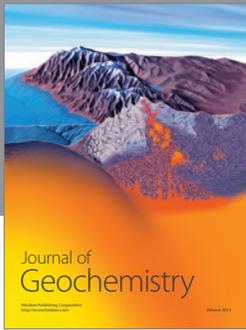
The authors declare that there is no conflict of interests regarding the publication of this paper.

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