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# Rain Height Distribution Over Some Stations in Tropical Nigeria Based on Trmm Precipitation Data

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**Abstract:** To be able to estimate appropriately the fade margin required for an optimum performance of earth-space communication links, some meteorological factors that must be considered includes among others: the annual average of the zero degree isotherm (ZDI) and the rain height. It is desirable to have information about these parameters at specific locations but only the ITU-R recommendation is used right now over Nigeria and the locations where specific information is not available. In this paper, two years of precipitation data (TRMM 2A23) from the Tropical Rain Measuring Mission (TRMM) satellite's precipitation radar has been analyzed to establish the rain heights over some selected stations in the different geographical regions of Nigeria. The result gotten were compared with recommendation ITU-R P.839 and this showed that the value of rain height quoted by the ITU-R does not reflect the real values over these stations as these parameters are location dependent and so cannot be used to estimate the correct fade margins required for satellite communication. We have also compared the year – to – year variability of the rain height and observed only a slight variability over the two years studied.

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## 1. INTRODUCTION

The performance of satellite communication systems depends on the propagation characteristics of the transmission medium. With the demand for increased capacity and improved services, the possibilities of meeting these users expectation can be inhibited by impairments due to some meteorological phenomenon like rain, fog, hail, clouds and the likes. In the design of satellite communication systems operating in the microwave and millimeter wave region, hydrometeors induced degradation (arising from rain and ice) poses a serious challenge to system availability at these frequencies (Ken'Ichi et al., 2004, Ajewole and Ojo, 2005, Mandeep and Hassan, 2006). The degradation can either be by absorption or scattering: absorption happens when the microwave energy is taken up by the medium leading to a reduction in the energy of the wave while scattering happens when there is a reflection of microwave energy out of the communication path by rain drops and this usually will cause the signals to go in directions different from the intended direction (Bohren and Huffman, Williams, 1995).

The ITU-R recommends that for proper planning of Earth-space communication systems, there is a need to have an adequate and up to date propagation data for use in the prediction techniques. Therefore, the ITU-R has a database for these heights during periods of precipitation and recommended this to be used in regions where location specific data are not available, but it has been established that these heights are location dependent (ITU-R P.618-10, 2009, Thurai et al., 2003, Mandeep, 2009) and so using the ITU-R quoted values will either lead to an over estimation or vice-versa as the case may be. Due to this, designers of communication systems operating at these frequencies and beyond need to have adequate propagation data in order to be able to estimate the appropriate fade margins required to meet these expectations ITU-R P.618-10, 2009), and these include the ZDI and the rain height.

Rainfall is a natural time varying phenomenon, more than half the solar energy incident on the Earth is absorbed by the ocean and land. This absorbed energy causes the evaporation of the water from the earth surface; the water vapour condenses aloft and then falls as rain (NASDA and NASA, 2011).

Awaka et al., 1998 developed an algorithm (TRMM 2A23) which is applied to the TRMM precipitation radar data and this gives two major classification of tropical rainfall; Convective and stratiform. This classification is based on the microphysical growth processes of precipitation particles and on the vertical distribution of latent heating associated with precipitation processes (Houze, 1995).

In this paper, detailed information on precipitation that can be compared with information obtained from the contour maps provided by the ITU-R and also, the suitability or otherwise of the of the ITU-R quoted values of rain heights for use in the estimation of fade margin for satellite communication in Nigeria is examined. The rain height over some selected locations chosen from the geographical regions of Nigeria as estimated from the ZDI values gotten from precipitation radar data on-board the TRMM satellite are presented. The ZDI is a region in the atmosphere where ice and water co-exist or the point where the ice–to–water transition begins to take place and this is known to be equivalent to ambient 0°C. Ice and water have differing propagation characteristics i.e. the reflectivity of liquid water is much higher than that of ice (Thurai, 2003).

## 2. LITERATURE REVIEW

Satellite communication links, particularly those operating at frequencies above 10 GHz are often degraded by hydrometeors (Allnutt, 1989), (Bryant et al., 2001) and the predictions methods used to calculate the extent of such degradation takes into account some meteorological parameters relating to the earth station location (Capsoni et al., 1987), (Kozu et al., 1989) and rain height is one of those indispensable parameters. Rain is known to have the most degrading effect on both terrestrial and satellite communication systems operating beyond the 10 GHz region.

Whenever radiowaves at these frequencies encounter hydrometeors like rain, they are degraded by absorption or scattering. The major factor in determining the degradation of microwave energy through rain is not determined by rain absorption but by the reflection of the microwave energy out of the communication path by rain drops which is known as rain scatter (Adrian, 2015).

There are two types of scattering; Rayleigh and Mie scattering. These are not different mechanisms but different models approximating the mechanism of radiowaves scattering at different wavelengths. There is wavelength dependence in scattering; waves with smaller wavelengths are scattered more than those with longer wavelengths.

In the tropical and equatorial climate, rain events are usually associated with convective cells which vertical dimension can reach much high altitudes (Mondal and Sarkar, 2003), (Kumar and Sarkar, 2007). About two-third of the world rainfall is assumed to happen in tropics,

The ITU-R radio communication group document 3/11E, (1995) states that information on the vertical structure and extent of precipitation is required for the prediction of attenuation and for the calculation of interference due to rain scatter. It also states that radar observations provide the only direct measurements of the vertical structure of precipitation of which rain is chief.

## 3. GEOGRAPHY OF NIGERIA AND RESEARCH DATA SOURCE

Nigeria, a tropical country located in West Africa stretches between 4.0°-14.0°N of latitude and 2.2°-14.3°E of longitude. Nigeria is a country of diverse landscape, and climates ranging from tropical rainforests to dry savanna lands (Exploring Africa, 2014). Nigeria's southern edge is a coastline along the Atlantic (known as the gulf of Guinea) and it is bounded by four other countries; Cameroon to the southeast, Chad to the northeast, Niger to the north and Benin to the west. Nigeria has two dominant seasons: the dry season locally known as harmattan or the Tropical Continental (CT) air mass influenced by the Northeasterly trade wind which blows across the Sahara desert runs normally from November to March; and the wet/rainy season known as the Tropical Maritime (MT) is influenced by the Southwesterly trade wind that blows across the Atlantic and runs from April to October. The seasons of Nigeria are not very much predictable but depends largely on the activities of the inter-tropical Convergence Zone (ITCZ), sometimes the seasons set in too early or too late depending on how the ITCZ moves. There is hardly a day in Nigeria without visible cloud cover but there is still anabundance of sunshine all through the year. The temperature experienced differs as one moves from one region to the other; the northern part of the country usually records the highest temperature values because of its proximity to the Sahara while the southeast and southwest enjoy mild temperatures because of their proximity to the Atlantic. The range of temperature in the north is much greater than in the south due to its desert-like environment. The various elevations and availability of water throughout the country produce awide variety of climates; Mangrove and fresh waterswamps along the coast and Niger delta with temperatures ranging from about 31 to 23°c, Tropical grassland/woodland savanna, and savanna in the north with temperatures ranging from about 44 to 6°C (degrees centigrade). The climatic environment changes from one part of the country to another.

The data used in this study was derived from the Tropical Rain Measuring Mission's Precipitation Radar satellite (TRMM-PR) measurements taken over two years (2010 and 2011) and downloaded from NASA's Goddard Earth Station Data Information Service Centre (NASA GES DISC) website over six locations across the geographic regions of Nigeria and the measurements covers 24 hours each day. TRMM 2A23 algorithm was used in this study. The TRMM satellite was launched in 1997 as a collaborative effort between the National Aeronautic and Space Administration of America and the National Space Development Agency of Japan and it is the very first space mission dedicated to the observation of tropical rainfall. TRMM-PR operates at 13.8 GHz with a surface footprint of about 4.5 km in diameter and arange resolution of 250 m. it scans ± 17° to achieve a swath of about 220 km (Kummerow et al., 1998), (JEORC, 2014). The PR can provide rain height information which is useful for the radiometer based rain rate retrieval algorithm.

The 2A23 algorithm classifies the rain type as; stratiform, convective and others. It detects also isolated warm rain whose height is below the ZDI height and classifies this as warm rain. the main objectives of TRMM 2A23 algorithm is; to detect the Bright-band when it exists and the determination of the height at which they occur, classification of rain type, detection of warm rain, computation of the height of the ZDI and output the height of the storm top(Awaka et al., 1998).

## 4. DATA ANALYSIS

The data granules used were downloaded from http://mirador.gsfc.nasa.gov, an average of 16 granules are captured per day and stored in compressed Hierarchical Data Format Earth Observation Satellite (HDF-EOS) format.

In downloading the data, the coordinates of the studied locations is used to acquire the location specific data.

The compressed HDF-EOS data of the TRMM 2A23 was extracted and opened using Matlab 2009A. The required parameter is selected and exported to a spreadsheet program for analysis. Figure 1 shows the typical raw data in Microsoft excel program.

Analyzing the data involves distinguishing between valid and invalid data and computing the mean value for each day. The data is averaged daily and the daily data is averaged to get the monthly value and the average of this gives the annual value of the parameter.

## 5. RESULTS AND DISCUSSION

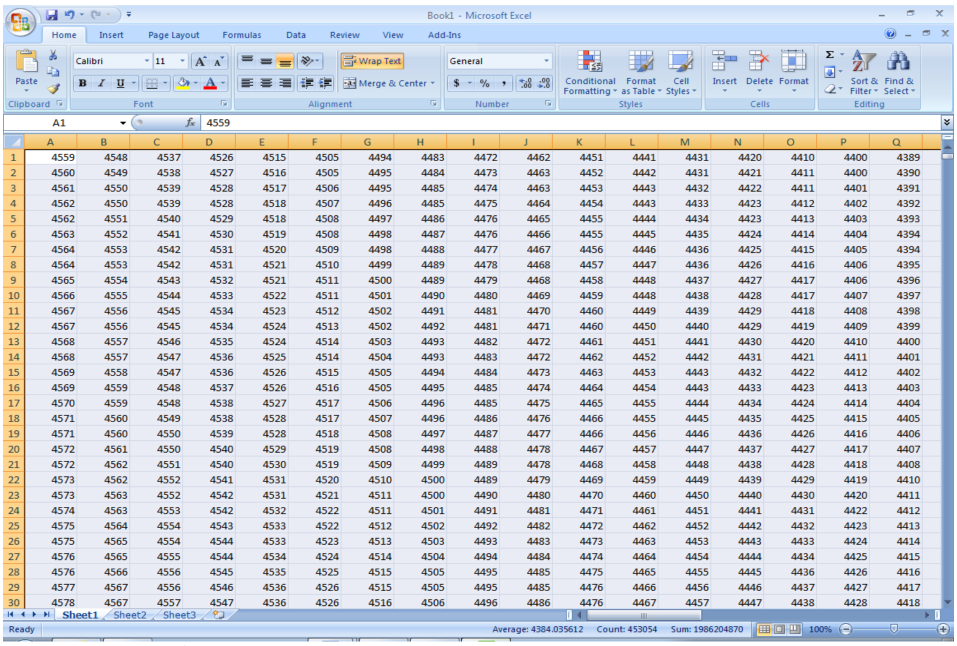
Rain height is a very important phenomenon to be considered in the estimation of the fade margin required for optimum performance of any earth-space communication system (Gregory, 1997). It is actually the height to which rain extends during periods of precipitation and it is assumed that rain is uniform from the ground to the rain height according to the simple vertical structure. It is also quoted to be that level up to which rain drops present have a diameter of 0.1 mm or more (Karmakar et al., 2011 and ITU-R P.839-3, 2011).

Recommendation ITU-R P.839-3 gives that the rain height can be gotten from the height of the 0°C isotherm using the relation;

$$h_r = h_0 + 0.36 \text{ km} \quad (1)$$

where $h_r$ is the rain height and $h_0$ is the height of the 0°C isotherm in km above mean sea level.

It has been established that rain height is location dependent and so the values cannot be generalized. In this work, two years (2010 and 2011) of TRMM-PR observation data taken over six locations chosen to represent each of the geographical and climatic regions of Nigeria have been analyzed to establish this parameter as specific to the locations. These locations are; Abuja, Akure, Bauchi, Enugu, Kaduna and Port Harcourt. The respective average rainfall (mm $h^{-1}$) over the stations are; 106.80, 112.67, 90.46, 114.49, 97.78, and 129.00 and climatic region are; Guinea Savanna, Rainforest, Sahel Savanna, Tropical Savanna, Sudan Savanna and Coastal respectively.



| | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 4559 | 4548 | 4537 | 4526 | 4515 | 4505 | 4494 | 4483 | 4472 | 4462 | 4451 | 4441 | 4431 | 4420 | 4410 | 4400 | 4389 |
| 2 | 4560 | 4549 | 4538 | 4527 | 4516 | 4505 | 4495 | 4484 | 4473 | 4463 | 4452 | 4442 | 4431 | 4421 | 4411 | 4400 | 4390 |
| 3 | 4561 | 4550 | 4539 | 4528 | 4517 | 4506 | 4495 | 4485 | 4474 | 4463 | 4453 | 4443 | 4432 | 4422 | 4411 | 4401 | 4391 |
| 4 | 4562 | 4550 | 4539 | 4528 | 4518 | 4507 | 4496 | 4485 | 4475 | 4464 | 4454 | 4443 | 4433 | 4423 | 4412 | 4402 | 4392 |
| 5 | 4562 | 4551 | 4540 | 4529 | 4518 | 4508 | 4497 | 4486 | 4476 | 4465 | 4455 | 4444 | 4434 | 4423 | 4413 | 4403 | 4393 |
| 6 | 4563 | 4552 | 4541 | 4530 | 4519 | 4508 | 4498 | 4487 | 4476 | 4466 | 4455 | 4445 | 4435 | 4424 | 4414 | 4404 | 4394 |
| 7 | 4564 | 4553 | 4542 | 4531 | 4520 | 4509 | 4498 | 4488 | 4477 | 4467 | 4456 | 4446 | 4436 | 4425 | 4415 | 4405 | 4394 |
| 8 | 4564 | 4553 | 4542 | 4531 | 4521 | 4510 | 4499 | 4489 | 4478 | 4468 | 4457 | 4447 | 4436 | 4426 | 4416 | 4406 | 4395 |
| 9 | 4565 | 4554 | 4543 | 4532 | 4521 | 4511 | 4500 | 4489 | 4479 | 4468 | 4458 | 4448 | 4437 | 4427 | 4417 | 4406 | 4396 |
| 10 | 4566 | 4555 | 4544 | 4533 | 4522 | 4511 | 4501 | 4490 | 4480 | 4469 | 4459 | 4448 | 4438 | 4428 | 4417 | 4407 | 4397 |
| 11 | 4567 | 4556 | 4545 | 4534 | 4523 | 4512 | 4502 | 4491 | 4481 | 4470 | 4460 | 4449 | 4439 | 4429 | 4418 | 4408 | 4398 |
| 12 | 4567 | 4556 | 4545 | 4534 | 4524 | 4513 | 4502 | 4492 | 4481 | 4471 | 4460 | 4450 | 4440 | 4429 | 4419 | 4409 | 4399 |
| 13 | 4568 | 4557 | 4546 | 4535 | 4524 | 4514 | 4503 | 4493 | 4482 | 4472 | 4461 | 4451 | 4441 | 4430 | 4420 | 4410 | 4400 |
| 14 | 4568 | 4557 | 4547 | 4536 | 4525 | 4514 | 4504 | 4493 | 4483 | 4472 | 4462 | 4452 | 4442 | 4431 | 4421 | 4411 | 4401 |
| 15 | 4569 | 4558 | 4547 | 4536 | 4526 | 4515 | 4505 | 4494 | 4484 | 4473 | 4463 | 4453 | 4443 | 4432 | 4422 | 4412 | 4402 |
| 16 | 4569 | 4559 | 4548 | 4537 | 4526 | 4516 | 4505 | 4495 | 4485 | 4474 | 4464 | 4454 | 4443 | 4433 | 4423 | 4413 | 4403 |
| 17 | 4570 | 4559 | 4548 | 4538 | 4527 | 4517 | 4506 | 4496 | 4485 | 4475 | 4465 | 4455 | 4444 | 4434 | 4424 | 4414 | 4404 |
| 18 | 4571 | 4560 | 4549 | 4538 | 4528 | 4517 | 4507 | 4496 | 4486 | 4476 | 4466 | 4455 | 4445 | 4435 | 4425 | 4415 | 4405 |
| 19 | 4571 | 4560 | 4550 | 4539 | 4528 | 4518 | 4508 | 4497 | 4487 | 4477 | 4466 | 4456 | 4446 | 4436 | 4426 | 4416 | 4406 |
| 20 | 4572 | 4561 | 4550 | 4540 | 4529 | 4519 | 4508 | 4498 | 4488 | 4478 | 4467 | 4457 | 4447 | 4437 | 4427 | 4417 | 4407 |
| 21 | 4572 | 4562 | 4551 | 4540 | 4530 | 4519 | 4509 | 4499 | 4489 | 4478 | 4468 | 4458 | 4448 | 4438 | 4428 | 4418 | 4408 |
| 22 | 4573 | 4562 | 4552 | 4541 | 4531 | 4520 | 4510 | 4500 | 4489 | 4479 | 4469 | 4459 | 4449 | 4439 | 4429 | 4419 | 4410 |
| 23 | 4573 | 4563 | 4552 | 4542 | 4531 | 4521 | 4511 | 4500 | 4490 | 4480 | 4470 | 4460 | 4450 | 4440 | 4430 | 4420 | 4411 |
| 24 | 4574 | 4563 | 4553 | 4542 | 4532 | 4522 | 4511 | 4501 | 4491 | 4481 | 4471 | 4461 | 4451 | 4441 | 4431 | 4422 | 4412 |
| 25 | 4575 | 4564 | 4554 | 4543 | 4533 | 4522 | 4512 | 4502 | 4492 | 4482 | 4472 | 4462 | 4452 | 4442 | 4432 | 4423 | 4413 |
| 26 | 4575 | 4565 | 4554 | 4544 | 4533 | 4523 | 4513 | 4503 | 4493 | 4483 | 4473 | 4463 | 4453 | 4443 | 4433 | 4424 | 4414 |
| 27 | 4576 | 4565 | 4555 | 4544 | 4534 | 4524 | 4514 | 4504 | 4494 | 4484 | 4474 | 4464 | 4454 | 4444 | 4434 | 4425 | 4415 |
| 28 | 4576 | 4566 | 4556 | 4545 | 4535 | 4525 | 4515 | 4505 | 4495 | 4485 | 4475 | 4465 | 4455 | 4445 | 4436 | 4426 | 4416 |
| 29 | 4577 | 4567 | 4556 | 4546 | 4536 | 4526 | 4515 | 4505 | 4495 | 4485 | 4476 | 4466 | 4456 | 4446 | 4437 | 4427 | 4417 |
| 30 | 4578 | 4567 | 4557 | 4547 | 4536 | 4526 | 4516 | 4506 | 4496 | 4486 | 4476 | 4467 | 4457 | 4447 | 4438 | 4428 | 4418 |



Fig. 1: Typical raw data in Microsoft excel program

The average yearly statistics of rain heights for the two years studied are presented for the observation periods of 2010 and 2011. For year 2010, we got 4.744 km, 4.732 km, 4.737 km, 4.722 km, 4.744 km, and 4.735 km for Abuja, Akure, Bauchi, Enugu, Kaduna and Port Harcourt respectively. For 2011 we recorded 4.650 km, 4.655 km, 4.635 km, 4.645 km and 4.618 km for Abuja, Akure, Bauchi, Enugu, Kaduna and Port Harcourt respectively. Fig. 2 shows the year-to-year variation of rain height over the locations studied and the ITU-R quoted value. The average values over the locations are; 4.697 km, 4.693 km, 4.686 km, 4.684 km, 4.695 km, 4.676 km for Abuja, Akure, Bauchi, Enugu, Kaduna and Port Harcourt respectively. The ITU-R predicted *hr* over all locations in Nigeria is put at 4.856 km.

It is observed that the rain heights are higher during the wet months as compared with the dry months which are in good agreement with earlier reported research that the ZDI heights are higher during periods of enhanced rain fall and rain height is almost coincidental with the ZDI (Mandeep, 2008), ITU-R P.839, (1990) also assumed that rain height corresponds to the ZDI height during rainy periods.

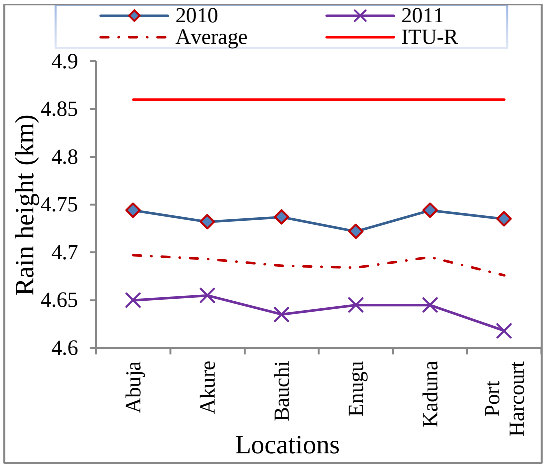



Fig. 2: Year-to-year variation of rain height over all the locations

## 6. CONCLUSION

The rain height over six selected stations in Nigeria has been studied and the values established. It has been shown that this parameter is absolutely location dependent as can be seen from the varied results gotten for the different stations studied and so the values quoted in the ITU-R document does not reflect the real heights over these stations and so not suitable for use in the estimation of fade margin needed for satellite communication systems. The year-to-year variability has been studied in relation to season, only a slight year-to-year variability has been observed. The data established in this research will enhance the prediction of the fade margin required for user availability requirements over the stations studied.

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