

PAPER • OPEN ACCESS

Geoclimatic characterization and latitudinal dependence of rain heights over Nigeria

To cite this article: Y B Lawal *et al* 2021 *J. Phys.: Conf. Ser.* **2034** 012010

View the [article online](#) for updates and enhancements.

You may also like

- [A new estimate for oceanic precipitation amount and distribution using complementary precipitation observations from space and comparison with GPCP](#)
Ali Behrangji and Yang Song
- [Tropical rainfall monitoring with commercial microwave links in Sri Lanka](#)
Aart Overeem, Hidde Leijnse, Thomas C van Leth et al.
- [The Effect of Magnetic Variability on Stellar Angular Momentum Loss. II. The Sun, 61 Cygni A, Eridani, Bootis A, and Bootis A](#)
Adam J. Finley, Victor See and Sean P. Matt



IOP | ebooks™

Bringing together innovative digital publishing with leading authors from the global scientific community.

Start exploring the collection—download the first chapter of every title for free.

Geoclimatic characterization and latitudinal dependence of rain heights over Nigeria

Y B Lawal¹, J S Ojo², S E Falodun³ and E O Olurotimi⁴

¹Department of Physics, University of Africa, Toru-orua, Bayelsa State, Nigeria

^{2,3}Department of Physics, Federal University of Technology Akure, Nigeria

⁴Department of Electronic and Computer Engineering, Durban University of Technology, Durban 4000, South Africa.

Corresponding e-mail: lawalyusuf.b@gmail.com

Abstract. Attenuation due to rain remains the most severe threat to terrestrial and satellite communication links in the tropics. Rain height is a precipitation parameter that plays important role in the determination of rain-induced attenuation. In this paper, a statistical study was carried out to establish the relationship between rain height and earth station latitude using rain heights derived from Zero Degree Isotherm Height (ZDIH) data retrieved from Global Precipitation Measurement (GPM). A strong positive correlation of 0.83 propelled the attempt to model equations for the estimation of rain height based on latitude. The research recommends a polynomial function of order 3 which has the best coefficient of determination (0.8). The annual mean values of rain heights were also computed and recommended for each of the four geoclimatic zones in Nigeria.

Keywords: Attenuation, Rain Height, GPM, ZDIH, Geoclimatic Zone

1. Introduction

It is generally known that transmission of radio signals at frequencies above 10 GHz is heavily degraded by raindrops in the tropics [1-4]. Unfortunately, the rapidly growing demand for wideband high-speed internetwork connection can only be fulfilled by transmitting radio signals at Super High Frequency (SHF) and Extra High Frequency (EHF). This great challenge has put researchers and engineers on their toes through the discoveries of several Fade Mitigation Techniques (FMT) such as site diversity, time diversity, and frequency diversity e.t.c. To choose and design any effective FMT during link budget calculations, it is important have an in-depth prior knowledge of rain attenuation magnitude at various transmission frequencies and percentage of time exceedance. The magnitude of rain-induced attenuation depends on certain parameters which include frequency, ground station-satellite elevation angle, slant path length, rain rate, rain height, polarization e.t.c. The non-rain parameters (i.e frequency, elevation, slant path length, polarization) tend to make rain-induced attenuation constant while the rain parameters (i.e rain rate and rain height) are responsible for the wide and sudden variations. Hence it is obligatory to study the trend of these parameters and provide effective prediction models for accurate determination of attenuation values. Rain height is the level up to which there are rain droplets with a diameter greater than 0.1 mm. It is the highest point level of rain region measured from sea level where supercooled



melted ice begins to fall as precipitation [5]. While rain rate can be measured directly with instrument, rain height can only be derived from other parameters. Generally, rain height is a localized parameter which can be estimated from zero degree isotherm height (ZDIH) otherwise known as freezing height level (FHL). To be precise, specific attenuation may be modeled as being constant from the surface to a height (rain height) near the 0°C isotherm level which must also be statistically estimated [6]. This confirms the relevance of rain height in the estimation of rain-induced attenuation. The relationship between rain height and ZDIH is given by ITU R P.839-4 as [7];

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

where h_o is the zero-degree isotherm height above mean sea level obtainable from ITU-R P.839-4 map. Several research works have proved that rain heights estimated based on the ITU-R map of ZDIH are not accurate globally. Moreover, recent ZDIH measurements from satellite-borne and on-ground precipitation radars have also corroborated this claim. For instance, the ITU-R P.839-4 map recommends rain height of 4.86 km for the entire tropical zone whereas [2, 5, 8-9] (Mondal and Sarkar (2003), Mandeep (2009), Ojo 2018, Lawal *et al.*, (2020) have proved that ITU-R value provides a poor estimation of rain height in some areas in the tropical region. The aim of this research is to model a localized equation for the accurate prediction of rain height based on GPM ZDIH and latitudes of some selected study stations in Nigeria. Several research works have reported a strong relationship between rain height and latitudes above 23° [10-16]. Most of this work recommends a constant rain height for low-latitude ($|\phi| < 20^\circ$) regions. [11] modeled the linear regression equations which recommend a fixed rain height of 4 km for areas with latitude less than 36° and $[4 - 0.075(\phi - 36)]$ for other regions. The model provides good results in the estimation of rain-induced attenuation for stations in Europe, U.S, and Japan but performed poorly in Africa.

Subsequently, CCIR [12] recommends 5 km for 23° latitudinal stations and $[5 - 0.0075(\phi - 23)]$ for stations above 23° latitude. Unfortunately, several succeeding kinds of research have proved that rain height is not fixed. The United States Federal Communication Commission recommends a fixed height of 5 km for low-latitude ($\phi < 23^\circ$) and $[5 - 0.075(\phi - 23)]$ for high-latitude regions in the southern hemisphere [15]. The recommendations are not absolutely accurate because recent researches have debunked the constancy of rain height over the equatorial region.

The works of [17] and [5] which utilized ZDIH from TRMM and GPM respectively have indicated that these models including ITU-R models underestimate rain heights in Nigeria. Moreover, The ZDIHs obtained from GPM data are higher than those obtained from TRMM and ITU-R map for the same location [18]. Hence, the need to formulate a localized equation for accurate prediction of rain heights based on the latitude of stations in Nigeria.

2. Data Source, Research Locations and Methodology

The data utilized for this research are the rain heights provided by Lawal *et al.*, 2020 for some selected locations in Nigeria. The rain heights were derived from the ZDIH extracted from the GPM database of the National Aeronautical and Space Administration (NASA) and Japan Aerospace Exploration Agency (JAXA). The data covers a period of six years from 2008 to 2013. The rain heights based on the available stations were increased to 37 stations by extracting more ZDIH data from GPM and following the procedure described in [5]. Table 1 presents the study stations and their associated parameters.

According to meteorological classification, Nigeria is broadly divided into four major zones

which are Sahel, Midland Savannah, Guinea Savannah, and Coastal zone [19]. The Sahel is the northernmost part of the country. This region is characterized by the predominance of tropical continental (cT) air mass over tropical maritime (mT) air mass annually. The cT period in the Midland zone is less compared to the Sahel but the humidity is usually higher due to localized convection and orographic effects. The Guinea savannah zone is associated with the dominance of mT air masses for about 7 months and cT for the remaining 5 months annually.

Table 1. The study locations and their characteristics.

Geoclimatic Zone	Station	Long (°E)	Latitude (°N)	Elevation (m)	Rain Height (m)
Sahel	Kaduna	7.43	10.52	250	5298
	Kano	8.50	11.5	488	5319
	Katsina	7.60	12.98	519	5363
	Gusau	6.67	12.17	463	5195
	Sokoto	5.23	13.07	318	5111
	Dutse	9.28	11.73	419	5308
	Birni-kebbi	4.20	12.45	228	5210
	Yola	11.93	9.91	599	5140
Midland	Bauchi	9.83	10.32	616	5247
	Maiduguri	13.15	11.83	320	5159
	Gombe	11.17	10.28	388	5256
	Jalingo	11.37	8.90	349	5205
	Damaturu	11.95	11.73	371	5233
	Makurdi	8.53	7.73	104	4966
	Lokoja	6.82	7.75	53	4906
	Ilorin	4.55	8.50	320	5162
	Lafia	8.52	8.48	205	5198
	Minna	6.55	9.62	251	5246
Guinea Savannah	Jos	8.90	9.92	1186	5335
	Abuja	10.00	9.00	360	5191
	Umuahia	7.48	5.53	152	4867
	Awka	7.73	6.20	142	4853
	Abakaliki	8.10	6.33	300	4950
	Enugu	7.50	6.50	180	4856
	Owerri	7.02	5.48	75	4853
	Ado-Ekiti	5.22	7.62	455	5046
Coastal Zone	Ikeja	3.33	6.58	41	4898
	Abeokuta	3.33	7.15	66	4970
	Oshogbo	4.57	7.77	320	5050
	Ibadan	3.90	7.38	230	5153
	Akure	5.20	7.25	350	5205
	Benin	5.60	6.32	200	4860
	Asaba	6.18	6.75	49	4851
	Uyo	7.93	5.05	43	4862
	Calabar	8.32	4.95	32	4884
	Port Harcourt	7.00	4.75	65	4907
Yenagoa	6.26	4.92	8	4912	

The Coastal Region is the southernmost part of Nigeria which shares a border with the Atlantic Ocean. The tropical maritime (mT) air mass dominates for most period of the year due to its proximity to the ocean.

The rain heights presented in table 1 were correlated and regressed on the corresponding earth stations using exponential, linear, log-normal, polynomial, and power-law functions. The coefficient of determination, coefficient of correlation, and other statistical were computed and discussed in the next section.

3. Results and Discussion

3.1 Spatial Distribution of Rain Height Across Nigeria

Rain height varies significantly across all the stations studied due to the changes in the topographical and climatological properties of various stations. The results, as depicted in Figure 1, shows that rain height increases from the coastal zone (Southern Nigeria) towards the Sahel zone (Northern Nigeria) with a minimal irregular variation. Katsina, Kano, and Jos possess the highest Hr of 5.33, 5.31, and 5.33 respectively. Lower rain height prevails in the coastal region due to the nearness of the ground surface to sea level in this area. According to equation (1), areas with low land levels are associated with low Hr and vice versa [7].

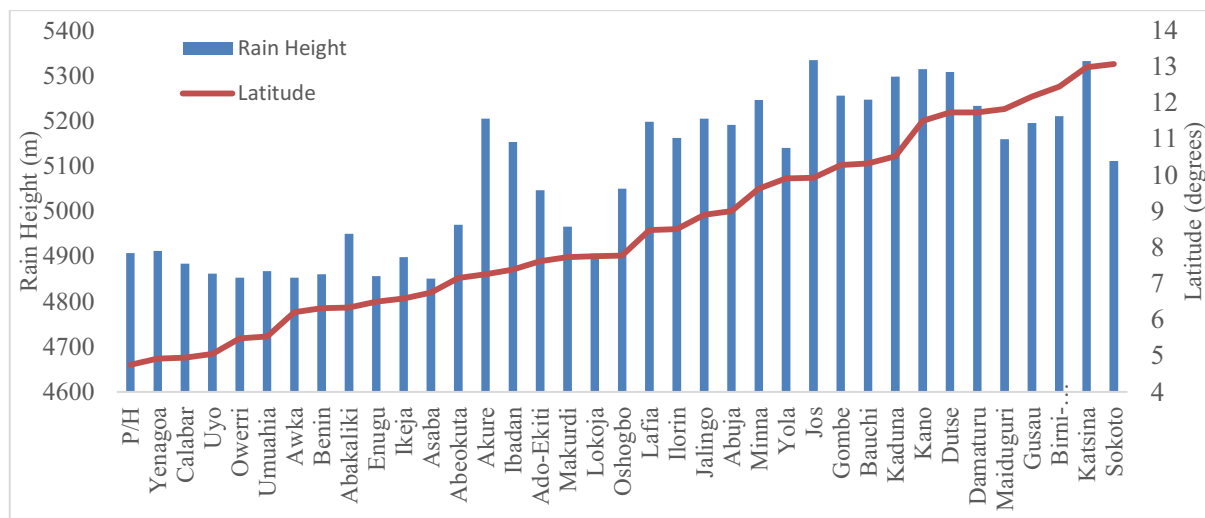


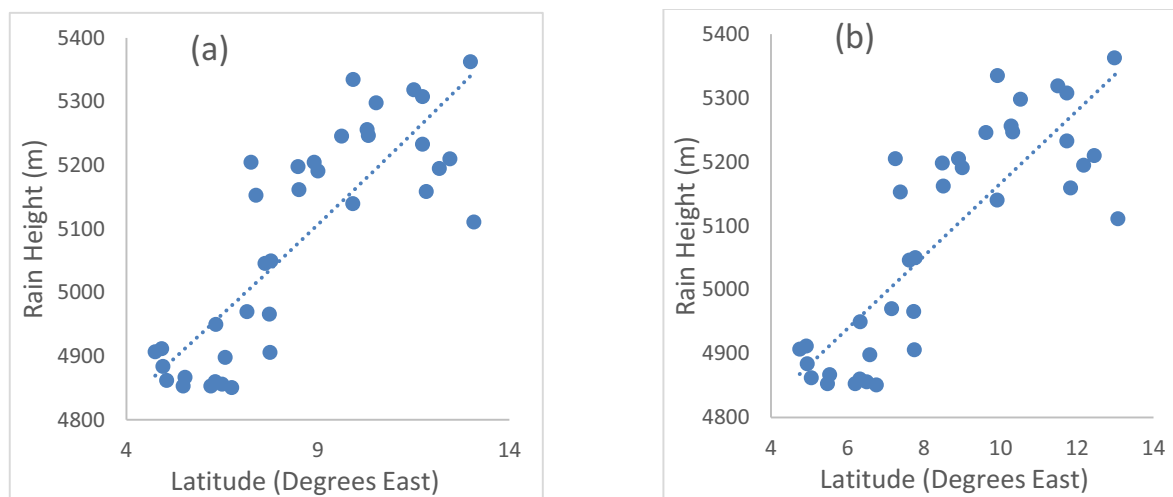
Figure 1. Spatial distribution of Rain Height across Nigeria

The Sahel stations possess the higher rain heights because the zone is largely dominated by tropical continental (cT) air masses hence, the prevalence of dry season for 6-8 months every year. Moreover, the latitudinal dependence of rain height is also responsible. However, the low value observed in Sokoto is due to the altitude of this station. The average rain height in this geo-climatic zone is 5.23 km. In the Midland zone, Hr is fairly stable at the mean value of about 5.2 km for Gombe, Abuja, Jalingo, and Bauchi. Jos is a special station situated on a plateau that is responsible for an abrupt spike up to 5.33 km in this zone. The high elevation of this station is mainly responsible for the rise in Hr compared with other stations. The annual mean Hr in the region was computed at 5.24 km with a standard deviation of

64.9 km. Similarly, the Hr in the guinea savanna zone reduces gradually with average annual values of 5.20, 5.16, 4.96, 4.07 km in Akure, Ilorin, Makurdi, and Lokoja respectively. Akure and Lokoja have the maximum and minimum rain height in this region. The overall annual mean for the guinea savanna is 5.06 km with a standard deviation of 145.7 km. The coastal area stations possess the lowest Hr when compared to all other stations in the country. This is due to the dominance of tropical maritime (mT) air masses for most periods of the year in this region [19]. This period, known as the intra-monsoonal period, is believed to be a consequence of several factors such as coastal upwelling and the northern advance of the subtropical high-pressure systems of the southern Atlantic Ocean. It is also caused by the circulation aloft, which becomes divergent and subsidence as a result of the frequent occurrence of inversions and isothermals in the upper atmosphere along the coast when the weather in the E1 zone makes its appearance a short way inland from the coast [20-24]. The annual rain height for Lagos, Port Harcourt, Calabar, and Warri are 4.89, 4.90, 4.88, and 4.85 km respectively. The annual mean rain height for the coastal zone stands at 4.89 km with a standard deviation of 0.024 km. The results provide better estimate of rain height, which is one of the input parameters for accurate prediction of rain-induced attenuation in each station and geoclimatic zone.

3.2 Latitudinal Dependence of Rain Height

A strong positive coefficient of correlation r which was found to be 0.83 exists between the two datasets (rain height and latitude). This corroborates the claims of previous works on latitudinal dependence of rain height on earth station altitude [6,11,25]. The positive result of r informed the decision to formulate regression equations for the prediction of rain height in Nigeria.



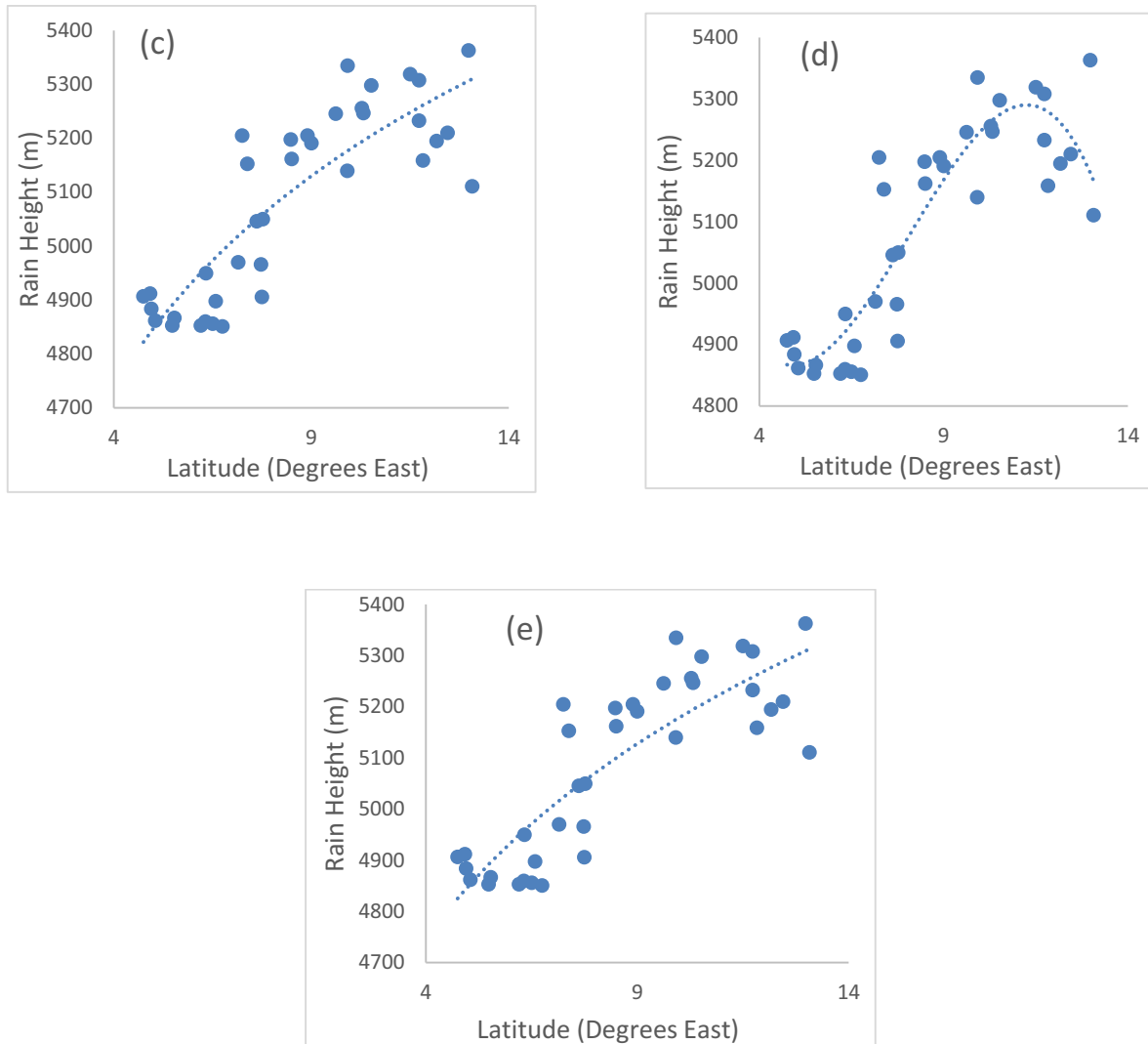


Figure 2: Models for regression of rain height on latitude in Nigeria; (a) Exponential Function (b) Linear Function (c) Logarithmic Function (d) Polynomial Function (e) Power Law Function

Figures 2-6: present the various trend lines fitted onto the scatter diagrams of rain height against latitude. All the regression equations produced good functions with coefficient of determination r^2 greater than 0.60. The modeled functions are presented in equations (2)-(6) with their corresponding r^2 .

$$H_r = 4616e^{0.0112\phi} \quad \langle r^2 = 0.69 \rangle \quad (2)$$

$$H_r = 56.85\phi + 4598 \quad \langle r^2 = 0.69 \rangle \quad (3)$$

$$H_r = 481.83\ln(\phi) + 4071.2 \quad \langle r^2 = 0.72 \rangle \quad (4)$$

$$H_r = -3.29\phi^3 + 79.82\phi^2 - 544.52\phi + 6005 \quad \langle r^2 = 0.80 \rangle \quad (5)$$

$$H_r = 4160.8\phi^{0.0951} \quad \langle r^2 = 0.71 \rangle \quad (6)$$

where H_r and ϕ are the rain height and latitude of the earth station respectively. Equation (5) has the best coefficient of determination and it is therefore recommended for prediction of expected rain height in any location in Nigeria.

4. Conclusion

Statistical analysis of the spatial distribution of rain height over Nigeria has been studied. The research revealed that rain decreases with latitude towards the southern part of Nigeria. The Sahel, Midland savannah, Guinea Savannah and Coastal zone possess mean rain height of 5.23, 5.23, 5.06 and 4.89 km respectively. The results obtained show that rain height has a strong positive correlation of 0.83 with latitude. The rain heights were regressed on latitude using various mathematical functions. The polynomial function with order 3 has the best coefficient of determination, hence the function is recommended for accurate prediction of rain height in Nigeria.

References

- [1] Ajayi G O and Odunewu P A 1989 Some characteristics of the rain height in a tropical environment. *IET Sixth International Conference on Antennas and Propagation, ICAP 89* **2**, Issue 301 pp 80-82.
- [2] Mandeep J S 2009 Zero Degree Isotherm Height for satellite communication in Malaysia. *Advances in Space Research* **43** Issue 6 p 984–989. <https://doi.org/10.1016/j.asr.2008.09.013>
- [3] Ojo J S 2014 Rain Height Statistics Based on 0° C Isotherm Height Using TRMM Precipitation Data for Earth-Space Satellite Links in Nigeria. *ISRN Atmospheric Sciences*, Article ID 798289 p 5. doi: <https://doi.org/10.1155/2014/798289>.
- [4] Yussuff A I 2016 Analysis of selected Earth-space Rain attenuation models for a tropical station. *International Journal of Electrical and Computer Engineering (IJECE)* **3** Issue 2 pp 383-391.
- [5] Lawal Y B, Falodun S E and Ojo J S 2020 Temporal Evolution of Atmospheric Parameter-Profiling on Rain Height Over Two Geoclimatic regions in Nigeria, *Journal of Atmospheric and Solar Terrestrial Physics (JASTP)*. **211** 105482. 1364-6826/©2020 Elsevier Ltd <https://doi.org/10.1016/j.jastp.2020.105482>
- [6] Crane R K 1980 Prediction of attenuation by rain. *IEEE Transactions on Communications*, **28** Issue 9 pp 1717-1733.
- [7] ITU-R P.839-4 2013 Rain height model for prediction methods. *P Series Radiowave Propagation. International Telecommunication Union, Radio-communication Section (ITU-R)*, Geneva, Switzerland
- [8] Mondal N C and Sarkar S K 2003 Rain height in relation to 0° C isotherm height for satellite communication over the Indian Subcontinent. *Theoretical and Applied Climatology* **76** pp 89–104.

- [9] Ojo J S and Owolawi P A 2018 Characterization of rain heights due to 0° isotherm in tropical and subtropical climates: implication on rain-induced attenuation prediction. *Journal of Theoretical and Applied Climatology*. <https://doi.org/10.1007/s00704-018-2382-z>
- [10] Goldhirsh J and Katz I 1979 Useful experimental results for earth-satellite rain attenuation modelling. *IEEE Trans Antennas & Propagation*, AP-27 pp 413–415.
- [11] García-López J A, Hernando J M, and Selga J 1988 Simple Rain Attenuation Method for Satellite Radio Links. *IEEE Transactions on Antennas and Propagation*, **36** Issue 3 pp 444–448.
- [12] CCIR 1990, Radioclimatological data, Report No. 563-4
- [13] Ajayi G O and Barbaliscia F 1990 Prediction of Attenuation Due to Rain: Characteristics of the 0° C Isotherm in Temperate and Tropical Climates. *Int. J. of Sat. Comm.* **8** pp 187–196.
- [14] Matricciani, E. (1993). Rain attenuation predicted with a two layer rain model. *Electron Lett (UK)*, **29**, 72–73
- [15] Federal Communication Commission 2002 Rain height as a function height earth-station latitude. *A Comprehensive Compilation of Decisions, Reports, Public Notices and other Documents of the FCC of United States*. FCC 02-116, pp 9748
- [16] Yussuff A I O and Khamis N H H 2013 Comparative analysis of bright band data from TRMM and ground radar data in Malaysia. *International Journal of Networks and Communications*, **3** Issue 4 pp 99-109.
- [17] Ojo J S, Ojo O L, and Joseph-Ojo C I 2014 Rain height information from TRMM precipitation radar and micro rain radar for radio communication studies in Nigeria, *6th International Conference on Adaptive Science & Technology (ICAST)*, Ota. <https://doi.org/10.1109/ICASTECH.2014.7068104>
- [18]. Lawal Y B, Ojo J S and Falodun S E 2021 Rain Height Statistics From GPM Data For Satellite Communications Systems In Nigeria, *Institute of Physics (IOP) Conference Series: Earth and Environmental Science* 655 (2021) 012038. doi:10.1088/1755-1315/655/1/012038
- [19] Olaniran O J and Sumner G N 1989 A Study of Climatic Variability in Nigeria Based on the Onset, Retreat, and Length of the Rainy Season. *International Journal of Climatology* **9** pp 253-269
- [20] Adedokun J A 1978 West African precipitation and dominant atmospheric mechanisms. *Meteor. Atmos. Phys.*, **27** pp 289–310.
- [21] Adedokun J A 1986 On a relationship for estimating precipitable water vapour aloft from surface humidity over West Africa. *J. Climatol.* **6** pp 161–172
- [22] Balogun E E and Adedokun J A 1985 On the variations in precipitable water over some West African stations during the special observation period of WAMEX. *American Meteorological Society* **114** Issue 4 pp 772–776.
- [23] Balogun E E 1981 Seasonal and spatial variations in thunderstorm activity over Nigeria. *Royal Meteorological Society* **36** Issue 7 pp 192–197
- [24] Adeyemi B and Joerg S 2012 Analysis of Water Vapor over Nigeria Using Radiosonde and Satellite Data, *Journal of Applied Meteorology and Climatology*, **51** pp 1855
- [25] Thurai M and Iguchi T 2000 Rain height information from TRMM precipitation radar, *Electron Lett (UK)*, **36** pp 1059-1061