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Recent Update on One-Minute Rainfall Rate Measurements for Microwave Applications in Nigeria

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Abstract: Rain rate statistics is required for planning both satellite and terrestrial links, especially in the microwave and millimeter wave bands. Presented in this work is the one-minute rain rate statistics observed over seventeen months using an electronic weather station - Davis Vantage Vue. The installation is at the main campus of Osun State University, Osogbo (7° 76' N, 4° 60' E), Nigeria. The cumulative rain rate distribution from the measured rain rate is presented alongside predictions by other prominent models. The $R_{0.01}$ estimate as high as ~ 120 mm/h was obtained from the surface data and subsequently employed in estimating the fade margin over a hypothetical DTH link for the reception of digital television content at 12.245 GHz from EUTELSAT W4/W7. Estimates presented over time percentages ranging between 0.001% and 1% are dissimilar. However, their suitability for predicting fade margins over this location could be ascertained via a performance analysis, based on experimental attenuation estimates over the link. The first point rain rate estimate from surface data over Osogbo is reported here and will be very useful for modeling rain attenuation and for planning both terrestrial and earth-space microwave links.

Keywords: One-Minute, Rain Rate Statistics, Rain Attenuation, Earth-Space Microwave Links, Point Rain Rate

1. Introduction

Rainfall is a major climatic factor and its variability plays several disturbing roles in a number of activities ranging from the transmission of radiowave signals to malaria epidemiology[1]. Among other similar disturbing factors is the hail [2], which is one of the most terrible natural disaster with severe impacts on mankind. For the propagation of radiowave signals however, attenuation due to rain remains a major loss factor required for planning communication systems and it affects applications operating within the microwave (3-30 GHz) and millimeter wave (30-300 GHz) bands, particularly for frequencies beyond 10 GHz [3-5].

Although rain is not the only form of precipitation affecting signal propagation in this band, it accounts for the most severe impairment on transmitted signals than other atmospheric components such as snow, fog, cloud, water vapour, fog, etc. [6-10]. The propagation path, to and from the satellites is actually well-defined through the earth's atmosphere, where the transmitted signal attenuates, scatters, refracts and depolarizes [11]. Most of these propagation mechanisms are however rain induced and more pronounced in tropical climates where rainfall is characterized with high intensity events.

Rainfall data logged in one-minute integration time is considered suitable for monitoring the rapid attenuation fluctuation on the radio path. Earlier studies have presented useful tools for planning satellite and terrestrial microwave links over Nigeria [12, 13], the one-minute rain rate estimates presented were deduced mainly from satellite data. Interestingly, a recent comparison by Ojo and Omotosho in [14] however reveals that one-minute rain rate estimates derived from ground data generally performs better than those obtained from satellite data. Since the dearth of ground data, particularly in the required one-minute integration time is still a concern to radio scientists and engineers, the cumulative rain rate distribution derived from ground-based observations in Osogbo will therefore provide a useful update.

Moreover, several rain rate models have been developed from long term precipitation statistics over different locations. Prominent among others are those developed from data collected in Brazzaville, Congo [15], those developed from a data bank containing 290 data sets for 30 countries [16], those predicting rain rain rate based on local climatological data available over any location [17], and the global ITU-R rain rate model as recommended in [18]. These models have been useful for the prediction of the cumulative rain rate distribution for selected locations in Nigeria [13, 19-21]. The radio climatological data required to ascertain their suitability for predictions over Nigeria is still sparse. Investigations on the performance of such models over some tropical sites however reveals that the rainfall rates derived using such models are either overestimated or underestimated [19, 21]. However, the implication is as stated in [22], where over-prediction is considered to account for designs that are less effective in cost, while under-prediction limits reliability of the link. There is the need to update radio-climatological database for accurate propagation design purposes. This can be achieved through a deliberate and aggressive precipitation measurement campaign, using a network of rain gauge installations across Nigeria.

Besides, the knowledge of surface precipitation data would enhance reliable link planning, required to meet the increasing demand for bandwidth and multimedia services. Likewise, communication satellites retain backhaul obligations for broadband internet service provision and digital DTH distribution. The detailed estimate of the fade margins required to maintain the high quality content also depends on the local rain rate date. These satellites offer trans-border services through its large footprint (typically delivering contents or services across rural, sun-urban and urban settings). The apparent digital divide can therefore be minimized through a deliberate effort to provide reliable services using satellite. This also dictates the need for improved availability, especially for mission critical applications, where little or no downtime can be tolerated.

Generally, the attenuation induced by rain A (dB) is estimated from the knowledge of the rainfall rate R (mm/h), which is expressed as [6]:

$$A = aR^b l \tag{1}$$

where a and b are coefficients depending on the Drop Size Distribution (DSD), frequency, elevation angle, temperature of the raindrops and polarization of the radiowave, while l is the equivalent path length of the rainy region, and is usually set to be about 5 km on high elevation angle on the earth-space link [23, 24].

Since the accurate prediction of rainfall attenuation depends on the knowledge of the long-term local precipitation data over a particular area, the rain gauge installation at Osun State University, Osogbo is an addition to the South-western precipitation measurement network [4, 24-27] for propagation studies in Nigeria. Due to the short integration time requirement for radio propagation purposes, the daily precipitation measurement at the Osogbo Aerodrome has not been directly useful in this regard.

The analysis of the ground-based one-minute rain rate measurement at Osun State University, Osogbo, South-West Nigeria is presented in this work. The cumulative rain rate estimates derived from the seventeen-month observation is a useful update to the precipitation database required for radio-climatic studies and for estimating rain fade in the design of satellite and terrestrial microwave links.

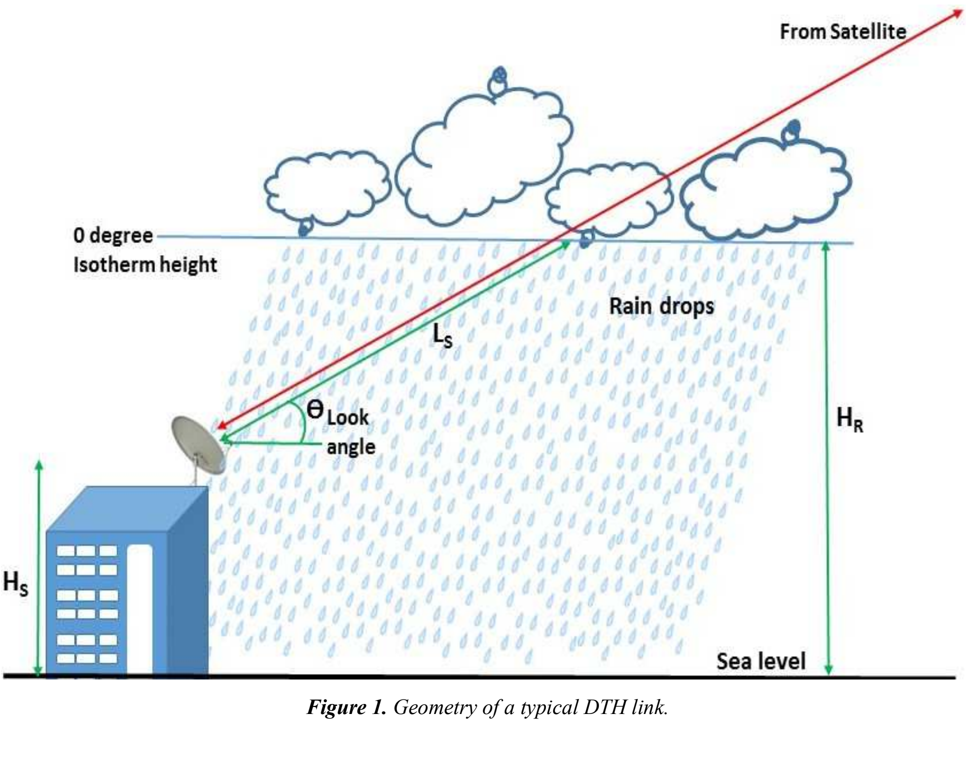

Figure 1. *Geometry of a typical DTH link.*

2. Rain Rate and Rain Attenuation Prediction Techniques

Several techniques have been employed for the prediction of rain rate over the years. They become very useful, particularly in locations where precipitation data are not available in the preferred short integration time format. Prominent among others are techniques developed by Moupfouma and Martins [15], Rice and Holmberg[17], Ito and Hosoya [16] and the ITU-R [18]. Estimates based on these techniques are compared with the measured rain rate statistics using the cumulative distributions predicted for Osogbo, Osun State.

The point rain rate estimate derived for Osogbo will remain useful for planning over terrestrial and satellite microwave and millimeter wave links, especially in other locations within the P zone of the rain climatic region, where such data do not exist. This knowledge is also employed for estimating the attenuation induced by rain on a typical Direct-To-Home (DTH) link for reception of digital television (TV) content via EUTELSAT W4/W7, geostationary at longitude 360 East. The selected models are the ITU-R model [6], Garcia model, Svjatogor model, Bryant model and the Australian model. Details of these models can be found in [28]. It is also important to investigate the suitability of these models. However, this will require an experimental data obtained over a period during – typically a year or more, at the earth station of a practical DTH link. The geometry of a typical DTH link is shown in Figure 1.

3. Experimental Site and Measurement

Rain gauge represents the most common equipment for the acquisition of surface precipitation data over a site. The data used in this work was obtained from a Davis Vantage Vue weather station, manufactured by Davis Instruments, Hayward, California, USA. The installation is at the rooftop of the College of Science, Engineering and Technology (CSET) building (about 360 m above sea level) at the main campus of Osun state University, Osogbo, Nigeria (7.760 N and 4.600 E). The weather station is a tipping spoon type and also measures and records data for other quantities such as temperature, relative humidity, wind speed and direction, all combined in the Integrated Sensor Suite (ISS). A sensor interface module (SIM) collects outside data from the ISS and transmits the data to a Vantage Vue console via low power radio at a frequency range of 868.0 – 868.6 MHz with a maximum line of sight distance of 300 m for reliable communication between the outdoor ISS and the indoor console. Figure 2 shows the measurement site in Osun State, South-Western Nigeria.

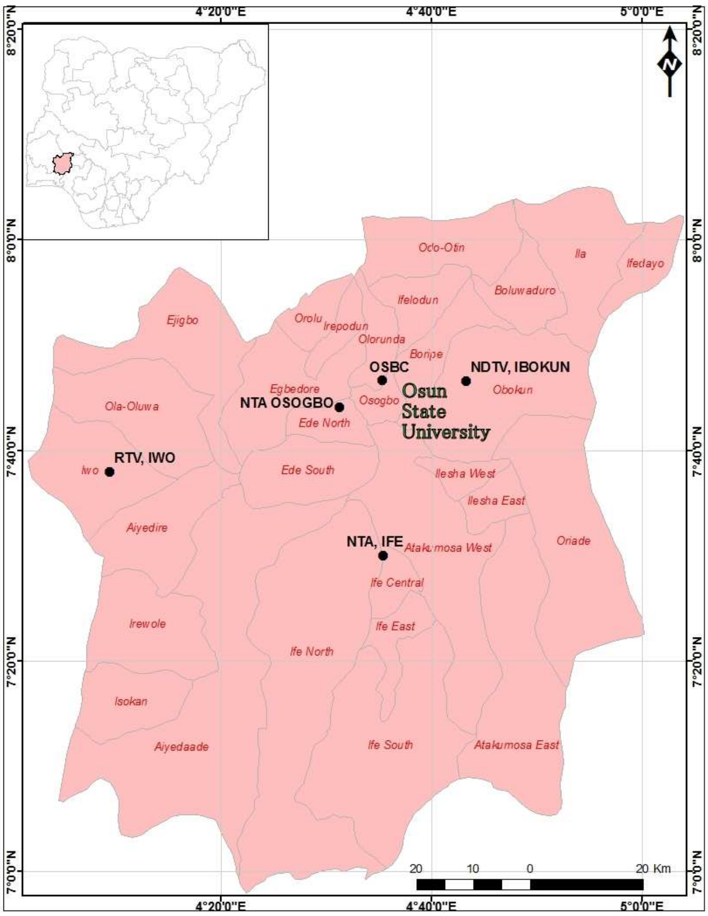

Figure 2. Map of Osun state showing the experimental site.

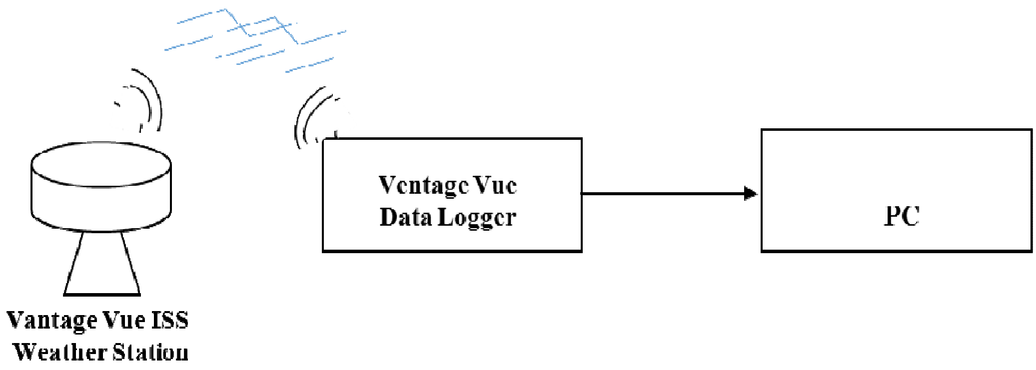

Figure 3. *Block diagram of the measurement setup at Osun State University, Osogbo.*

The accuracy of the gauge is ±1% at 1 litter/h with a measuring range of a minimum of 2 mm/h to a 400 mm/h. The gauge is accurate to within 2% up to 250 mm/h. Rainfall up to 400 mm/h is measured with the resolution of 0.2 mm. The data logger scans the data at every one second intervals and integrated over one-minute interval. The availability of the gauge is about 99.2 %. And the 0.8% unavailability is due to system maintenance and system shutdown as a result of power drain. The console incorporates a Weatherlink software and USB data logger that is synchronized with the personal computer, hence facilitating improved weather monitoring capabilities and a continuous data logging. The block diagram of the measurement setup is as shown in Figure 3.

4. Results and Discussion

The one-minute rain rate data collected using the Davis Vantage Vue weather station for the period between March 2013 and July 2014 was sorted and analyzed to provide the precipitation data required for rain attenuation prediction over Osogbo. Statistical analysis of the 17-month precipitation data is also presented here. The parameters extracted from the weather station include; rainfall rate for each month, number of one-minute rain rate recorded throughout the period and a number of other parameters.

Table 1. *Precipitation statistics for the 17-month observation.*

Month	Minimum rain rate (mm/h)	Maximum rain rate (mm/h)	Total rain rate (mm/h)	Number of rain duration	Number of one-minute rain rate recorded per month
March, 13	0.8	57.4	569.8	72	4914
April, 13	0.8	256	11759	940	18013
May, 13	0.8	122.9	5601.8	406	16768
June, 13	0.2	94.5	1618.7	303	20498
July, 13	0.8	286.6	4066.5	509	31470
August, 13	1.0	27.9	317.7	90	15633
September,13	1.0	87.6	7666	1041	28778
October, 13	0.8	281	5062	450	27894
November, 13	1.0	115.3	816	33	25994
April, 14	1.0	18	240.1	71	10520
May, 14	1.0	124	5401.3	1000	18820
June, 14	1.0	98.3	4434.2	283	11732
July, 14	1.0	190	5109.1	429	8860
Total	11.2	1759.5	52662.2	5627	239894

Table 1 shows the precipitation statistics for the observation period. The highest rainfall intensity was observed in the month of July, 2013 with an intensity of 286.6 mm/h, followed by October, 2013 with 281 mm/h. Usually, Rainfall in Nigeria is usually observed between the months of March and October. The minimum total rainfall intensity was recorded in November of 2013, while the highest was recorded in September, 2013. The total rain rate in August is low due to the "August break", which typically lasts for about 3 weeks.

The total number of one-minute rain rate recorded per month varies from 4914 to 31470. The lowest number was observed in March, 2013 with a total record of 4914, while July 2013 is said to the have the highest number with a total number of 31470 one-minute rain rate recordings. The total record taken for the whole 17-month observation is 239894.

Table 2 shows the number of days when rain accumulation is either equal to or less than 0.2mm. Stratiform rain type of longer duration is witnessed when rainfall accumulation is less than or equal to 0.2mm, much of these are observed in July and October 2013. On the other hand, when rainfall accumulation is greater than 0.2 mm, the convective rain type is said to be in occurrence. The month of April, 2013 and June, 2014 recorded a number of the convective rain type occurrence with 21 and 17 days respectively.

Figure 4 presents the comparison of cumulative distribution of the predicted rain rate and the measured rain rate. It is observed that the cumulative rain rate statistics is underestimated by the ITU-R prediction and this is pronounced at lower time percentages (0.001 – 0.1%). Apart from the sharp contrast observed below 0.01% of the time, predictions based on other selected models show better agreement with the measured data. The measured rainfall rates for the 0.01% is 120 mm/h. Rain rate estimates for the same time percentage for the ITU-R, MOUPFOUMA, RH and KITAMI models are 55 mm/h, 103.7 mm/h, 113.2 mm/h and 120 mm/h respectively.

Table 1. *Days one-minute accumulation exceeds or equal to 0.2mm.*

Month	Days one-minute acc. exceeds 0.2mm	Days 1-minute acc. tips equals 0.2mm
March, 13	6	15
April, 13	21	4
May, 13	4	9
June, 13	11	4
July, 13	5	21
August, 13	2	13
September, 13	8	12
October, 13	8	24
November, 13	2	11
April, 14	2	18
May, 14	15	13
June, 14	17	6
July, 14	4	15
Total	105	165

This result agrees with the estimate for Osogbo based on the ITU-R rain climatic zone [29], which groups Osogbo with other locations in the South-western part of Nigeria in the P zone. However, measurement is still ongoing at this station and the result will be validated from time to time.

Figure 5 shows the cumulative distributions of the rain attenuation predicted using the surface rainfall data for all the models selected. This presents the one-to-one hypothetical behavior of the rain attenuation models at varying percentages of the time and under the same design condition. 52.50 was maintained as the antenna look angle for typical reception of digital television content at 12.245 GHz via EUTELSAT W4/W7 satellite, which is geostationary at longitude 360 East. The attenuation induced by rain at 0.01% of the time is 16.2 dB, 14.75 dB, 14.56 dB, 10.61 dB and 5.46 dB respectively for ITU, Garcia, Australian, Svjatogor and Bryant models.

At lower time percentage, 0.001% of the time, the Garcia model presents the highest estimate of 29.8 dB. The Bryant model still retains the lowest estimate of 12.24 dB, while the Australian, ITU-R and Svjatogor models predicted 29.4 dB, 25.2 dB and 22.2 dB respectively.

The models show dissimilar estimates at lower percentages of the time and it is still difficult to present the model that outperforms all others in this scenario. Their performance can be better ascertained with experimental data obtained over a practical link.

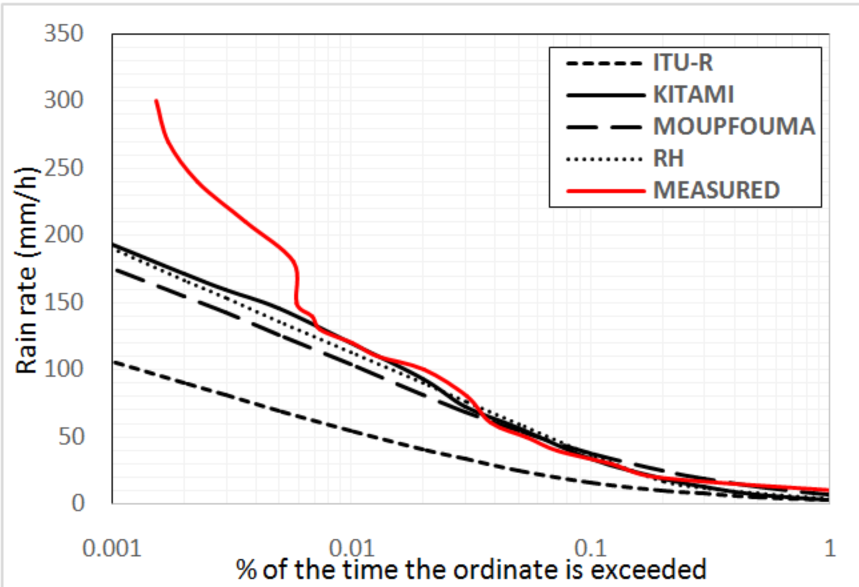

Figure 4. *Cumulative rain rate distribution over the observation period.*

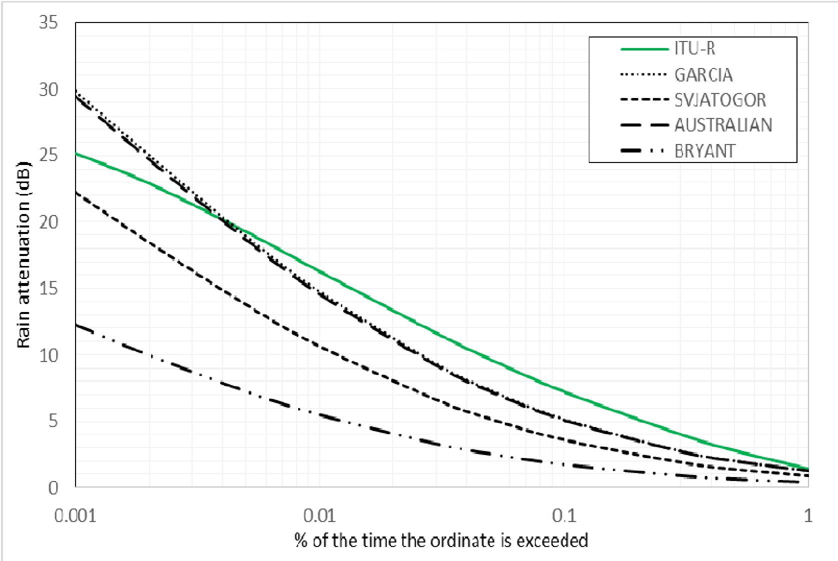

Figure 5. *Rain attenuation predicted for a typical DTH link (12.245 GHz, EUTELSAT 36B).*

5 Conclusions

In the quest to reduce the problem of rainfall attenuation and to update global precipitation database for radio-climatic and other applications, the first point rain rate estimate from surface data collected in Osogbo is presented here and will be very useful for modeling rain attenuation and for planning both terrestrial and earth space microwave links. The rainfall rate exceeded at 0.01% of the time is estimated as 120 mm/h for the 17-month observation, and this estimate was employed in predicting the attenuation induced by rain over a hypothetical DTH link for digital television reception at 12.245 GHz. Estimates presented over time percentages ranging between 0.001% and 1% are dissimilar. However, their suitability for predicting fade margins over this location could be ascertained via a performance analysis, based on experimental attenuation estimates over the link. Interestingly, precipitation measurements is ongoing at this station and the result presented is a useful tool for national and regional communication link designs.

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