On the conversion of a 3-hour integration time rain rate into one minute rain rate for forecast of attenuation due to rain

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Abstract. Degradation of satellite signal due to rain at Ku-band and higher frequencies are of much importance to the radio science community. This calls for a continuous effort in the development of a 1-min rain rate conversion model from 180-min (3 hours) integration time which would be helpful in the utilization of such data in the generation of 1-min rain rate towards rain attenuation calculation from the available attenuation models. This paper has therefore presented a formula that converts a 180-min (3 hours) rain rate to its 1-min equivalent rain rate.

Keywords: Wave propagation, Signal transmission, Integration time, Rain rate.

1. Introduction

The increasing demand for internet and multimedia networks has contributed immensely to the growth of satellite communications [1-2]. The earth-space and satellite communication to the ground systems are severely affected by heavy precipitation over a tropical location such as Nigeria. The major rain-induced propagation impairment above 10 GHz is rain attenuation, which causes severe signal degradations. This is a challenge to radio engineers. A reliable and correct ground data collection is needed to enhance a better conversion model which would be used for validation purposes. Since it is mostly impossible to obtain ground data for all locations of interest in a prospective research study, it is very imperative to effectively utilize satellite data archive and develop a reliable and accurate method of conversion to a one-minute equivalent so that radio engineers could come up with schemes that will combat rain attenuation to boost signal availability at all times. Three hours rain rate integration time can be converted to 60 seconds integration time rain rate data using some well-established conversion techniques. [3] presented a general and more reliable method from integration times of 5 minutes, 30 minutes, and 60 minutes for temperate, tropical and cold climates in which its performance was rated to be better than the ITU-R conversion method. [4] endeavoured to come up with a prediction technique through the usage of experimental local data in the effective utilization of the available rain attenuation models. An effort has been made using techniques like physical, empirical, and analytical in the conversion of rainfall data from higher integration time to the lower integration time [5]. Also, efforts have been made by [6, 7, 8, 9] in developing one-minute rainfall rate statistics for Nigeria for effective utilization by radio engineers. Over the years, efforts were made to predict the rain rates through some developed and available techniques. These prediction techniques
are quite essential for a particular region where the rainfall data are not available. Researchers like [10,11,12] have made a huge impact on the development of techniques for the estimation of one-minute integration time rain rate and rain attenuation. The estimation of one-minute rain rate integration was developed through a 3-hour Tropical Rainfall Measuring Mission (TRMM) rainfall rate data and measured rain rate data via the predictive technique of cumulative distribution for Akure, South-Western Nigeria. Consequently, the model was tested for other regions in the Southern region of Nigeria with available measured rain rate records for performance evaluation. The objective of this research is to develop a reliable method of conversion of rain rate from a 3-hourly rain rate integration time obtained from TRMM satellite to one-minute rain rate data over Nigeria. The performance of the proposed model has been compared with existing models. The derived one-minute estimated rain rate would be adequate for the effective installation and building of a reliable earth-space communication link by radio engineers within the South-Western region of Nigeria.

2. Data and Methodology

Archived ground-based measured rain rate data collected from the Davis Vantage Vue weather station installed at the Department of Physics, Federal University of Akure (7.17°N and 5.18 °E) has been utilized in this study. The weather station comes with a tipping spoon and as well takes data stamps of temperature, relative humidity, wind speed, and direction which are embedded in a unit called integrated sensor suite (ISS). In this work, rainfall rates of 3 hours integration time obtained from the TRMM satellite and one-minute ground data measured from rain gauge were utilized for the modelling of the one-minute integration platform. The following models namely, the power model, exponential model and the logarithmic models have been used to convert the 3-hour rain rate to a 1-minute rain rate. The performance has also been investigated from the rain rate statistics. \( R_I(P) \) is the rainfall rate exceeded for an integration time of 1-min with an occurrence possibility of \( P \), while \( R_\tau(p) \) represents the rainfall rate in \( \tau \) min time integration, and \( a \) and \( b \) which are being referred to as conversion coefficients are obtained statistically from the rainfall data.

\[
\text{Power model: } R_I(p) = a \left[R_\tau(p)^b\right] \\
\text{Exponential model: } R_I(p) = a \times e^{b[R_\tau(p)]} \\
\text{Logarithmic model: } R_I(p) = a + b \times \ln[R_\tau(p)]
\]

There are mainly four seasons that have been observed over Nigeria (pre-monsoon (Mid-March to April), Intense (May-September), Cessation (October to mid-November), and dry (mid-November to mid-March)). Major rainfall has been observed in an intense period. In this study, the rain rate characteristics have been investigated over the above regions mentioned in table I and for the 4 seasons.

3. Results and discussion

The power-law, exponential and logarithm conversion methods have been applied on the rainfall rate statistics of 180-min obtained from TRMM satellite data \( (R_P) \) to fetch the predicted 1-min rainfall rate of the same probability of time and compared with the measured one-minute rainfall rate \( (R_M) \). The error calculation of the above three methods has been analyzed using equation 4.

\[
\text{% error} = 100 \times \frac{(R_M) - R_P}{R_M}
\]

The power-law model shows better performance compared to the other two models. At 0.01% of the time, the measured and model-predicted rain rate is 112 mm/h and 110 mm/h respectively and the error is 1.82%. In the following steps, the power-law model has been chosen for this study.

Fig. 1 shows the cumulative distribution of rain rate obtained from the above three models and compared with the measured rain rate data. Fig. 2 shows the power-law fit of the 1-min measured rain
gauge rain rate data and the 180-min TRMM rain rate data for the same time integration over Akure. It has been observed that TRMM 3-hour data show lower values compared to the measured rain rate. It is quite expected, as the rainfall data calculated from the TRMM satellite is 0.25°X0.25°.

Figure 1: Cumulative distribution of rain rate distribution for the measured, power model, exponential model and logarithmic model.

Table 1 presents the statistical analysis performed on the models under test to measure the accuracy. From Table 1, it is shown that the power model performed better with a minimum error rate when compared to the other models.

Figure 3 depicts the combined rain rates for all the areas under study. At 0.01% of the time, rain rates of 110 mm/hr, 122 mm/hr, 121 mm/hr, 124 mm/hr, and 125 mm/hr have been observed for Akure, Abeokuta, Osogbo, Ogbomosho, and Ile-Ife respectively.

Table 1: Model, prediction error and Mean Square Error (MAPE)

| Model           | Prediction error (%) | MAPE (%) |
|-----------------|----------------------|----------|
| Power           | 1.79                 | 1.79     |
| Exponential     | -127.7               | 127.7    |
| Logarithmic     | 35.7                 | 35.7     |
Figure 2: Equiprobable rain rate statistics between 1-min measured data and 180 minutes TRMM data.

Figure 3: Combined rain rates for the five investigated areas

The seasonal analysis of rainfall rates of the investigated sites has been shown in Figure 4. In Akure, the intensive season is marked with the highest rainfall rate of 110 mm/hr, followed by pre-monsoon with a rainfall rate of 90 mm/hr while dry and cessation revealed rainfall rates of 80 mm/hr and 70 mm/hr for 0.01% of the time. However, the pattern of Abeokuta’s rainfall rate is same for the intensive and pre-monsoon seasons. The rainfall rates at dry and cessation seasons are 70 mm/hr and 60 mm/hr respectively. Analysis of the seasonal rainfall rate in Osogbo revealed that the cessation season had a higher rainfall rate of 80 mm/hr when compared to its dry season counterpart with a rainfall rate of 70 mm/hr. However, the intense and pre-monsoon season exhibited equal strength of rainfall rate of 100 mm/hr for 0.01% of the time. In Ogbomosho, the cessation season showed a rainfall rate value of 80 mm/hr which is higher than its dry season regime with a 70 mm/hr rainfall rate. The intense season marked a rainfall rate of 100 mm/hr while the pre-monsoon season exhibited a rainfall rate of 80 mm/hr for 0.01% of the time. However, Ile-Ife revealed 90 mm/hr and 70 mm/hr rainfall rates regimes for cessation and dry seasons while the intense season still showed a higher pattern of rainfall rate of 110 mm/hr when compared with the pre-monsoon season with a rainfall rate of 100 mm/hr for 0.01% of the time.
Figure 4: Seasonal distribution of rain rate in (a) Akure and (b) Abeokuta (c) Osogbo (d) Ogbomosho, and (e) Ile-Ife over the observation period

4. Conclusion
This paper has presented the seasonal, rainfall rate statistics for some locations in a tropical environment in the South-Western region of Nigeria. However, an attempt has been geared at the development of a reliable and efficient formula for the conversion of a 180-min (3 hours) rainfall rate to its 1-min equivalent rainfall rate. This will be helpful towards the conversion of long-term rainfall rate data from 180-min (3 hours) to an equivalent of 1-min rainfall rate, which is a key factor for the effective utilization of different models used in the prediction of attenuation due to rain.

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