Performance analysis of the synthetic storm technique rain attenuation prediction model on Nigerian climate

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Abstract. This study analyzes the performance of the synthetic storm technique (SST) over the Nigerian climate. The location of interest was 9.91˚N, 8.88˚E. Two months rain rate time-series data measured by a rain gauge located inside the University of Jos, Nigeria was utilized for the purpose of this work. The analysis is based on the time-series seasonal variation of rain statistics. Comparison was made between the SST model and measured values at 12.519 GHz for signal downlink from NIGCOMSAT-1R satellite. From results obtained, we observe peak predicted rain attenuation by SST model was 4.06dB with a minimum of 0dB for the month of June while the peak rain attenuation for July was 6.92dB. It can be observed that the SST predicts closely with measured rainfall values. However, disparities exist between the calculated attenuation and the measured values for a few rainfall events. The SST model performance was satisfactory for the period under observation.

1. Introduction
The synthetic storm technique (SST) model was proposed by Matricciani, (1996), the model is used to convert instantaneous rain rate into attenuation under some assumptions which include rain rate time series recorded from the location under study and on modeling the vertical structure of rainfall with two effective layers.

Above 10 GHz, high signal attenuation due to rainfall is prominent as seen from studies from Yun and Iskander, (2015); Yin et al, (2015); Yin et al, (2017); Aviles and Kouki, (2016). The SST model has successfully been used by a number of studies to predict attenuation especially for tropical locations. However, experimental data for rain attenuation in the development of channel models to predict attenuation are scarce and exist only for few sites and frequencies.

In this study, validity of the SST method is tested for the time series prediction of attenuation due to rainfall for Ku band (12.519 GHz) for the tropical location Jos, Nigeria. Daily variation of rainfall rates and attenuation are compared with the actual measured statistics. Sensitivity of the storm speed on SST implementation for short term periods are also examined.

2. Experimental data and study location
Propagation measurements over an earth-space path has been carried out at 9.91˚N, 8.88˚E, Altitude: 1217 m, the location is tropical in nature. The procedure involved receiving a Ku band signal at frequency 12.519 GHz from NIGCOMSAT-1R at 42.5˚E. The setup also includes rain
rate measurements from a rain gauge co-located with the beacon receivers. The recorded rain rate and attenuation data are passed through in-built raised square cosine filters to eliminate effects from scintillation. In this study, the measurement period was from June 2020 to July 2020. This is done in order to show the results of individual events and monthly statistics. The foremost common sort of precipitation in this region throughout the year is rain alone, with a peak probability of 78% on 4th August. The wetter season spans a period of 5.5 months starting from 21st April to 7th October. The tiniest chance of a wet day is usually experienced on 30th November. Dry spells of no rain usually last about 4 to 5 from ending October to ending March. In order to show variation in rain rates for different days of the months as against total rainfall rates for the months, we show the total rainfall for a 31-day period centered on every day of the month. The location of study also experiences the coldest day of the entire year on 29th December with a mean low of 11.66 °C and high of 28.89 °C. Over the course of the year, the temperature typically varies from 11.66 °C to 33.33 °C and isn't below 8.89 °C or above 36.11 °C. The smallest amount of rain falls around 20th December, with a mean total accumulation of 0.0 mm. The rainy period of the year lasts for 7.2 months, from 24th March to 31st October, with a sliding 31-day rainfall of a minimum of 12.7 mm. The foremost rain falls during the 31 days centered in July and August 10 had a mean total accumulation of 208.28 mm.

2.1 Synthetic Storm Technique (SST)

One of the merits of the application of the SST method is the ability of the technique to use rainfall time series estimates which are based on dual-layer representation of rain due to the melting layer. The SST is capable of estimating multivariate rain attenuation distributions simultaneously for distant sites which can be useful for the design of satellite systems. Matricciani and Riva (2005); Kanellopoulos et al (2006) The value of rain as a function of length to the wind direction can be described with SST. Applications of SST also depend on factors such as: advection velocity Drufuca (1974). Other input parameters required by the SST model for rain attenuation prediction include: The base station altitude, Rain height, Melting layer characteristics and Elevation.

3. Materials and methods

The SST converts a rain rate time series recorded at a given location into a signal attenuation time series. The conversion requires the knowledge about the length of the signal path through the rain cell, the storm speed (ν) and the rain rate for the location under study. The physical and mathematical fundamentals of the method are described in Matricciani, (1996). The schematic rain structure based on the SST is shown in Figure 1.
The vertical structure of the precipitation medium is modeled with two layers. Layer A with raindrops at 20°C and layer B with melting hydrometeors at 0°C. The Specific attenuation $x_0$ proposed by Olsen et al., (1978) is given as:

$$\gamma(x_0) = k R^{a}(x_0)$$  \hspace{1cm} (1)

with $k$ and $a$ necessary to relate rainfall rate to specific attenuation (dB/km) Maggiori, (1981)

Variation of signal attenuation with time can be gotten by changing $x_0$ according to the advection speed $v$ of the rain cell such as:

$$x_0 = v * t$$  \hspace{1cm} (2)

With signal attenuation along the satellite path given as:

$$A(x_0) = k_A \int_{0}^{L_A} R^{x_A}(x_0 + \Delta x_0, \xi) d\xi + k_B \int_{L_A}^{L_B} R^{x_B}(x_0, \xi) d\xi$$  \hspace{1cm} (3)

$L_A$ and $L_B$ = radio path length due to layer A and B respectively

$\Delta x_0$ = shift due to the presence of layer B.

Altitude above sea level of the earth station is $H_s = 1217 m$

$H_B$ and $H_A$ are calculated as follows:

$$H_B = 5 \hspace{0.5cm} \emptyset < 23^\circ$$  \hspace{1cm} (4)

$$H_B = 5 - 0.075(\emptyset - 23) \hspace{0.5cm} \emptyset \geq 23^\circ$$  \hspace{1cm} (5)

$h = 450 m$ (For the location of interest)

where $h =$ depth of the melting layer

Effective rain height is given as:

$$H_\emptyset(\emptyset) = H_B(\emptyset) - h$$  \hspace{1cm} (6)

Recall $h = 0.45 km$ and $H_B$ given by (4)

Temperature of the melting hydrometeors (Layer B) is assumed to be 0 °C with the temperature of the raindrops (Layer A) assumed to be 20 °C. A combination of equations (4) and (6) can be used in the characterization of all rain events made up of the two main types of precipitation described by meteorologists, which include stratiform and convective. Houze, (1981).
Calculating for $L_A$ and $L_B$ we obtain:

$$L_A = \frac{H_A - H_S}{\sin(\theta)} = 4.93 \text{ km}$$

$$L_B = \frac{H_R - H_S}{\sin \theta} = 5.6 \text{ km}$$

The relationship between the rain rate of layer A and layer B can be described as:

$$R_B = r R_A$$  \hspace{1cm} (7)$$

with $r = 3.134$

$$L_B - L_A = 0.67 \text{ km}$$

By applying Fourier transforms to equation (3) we arrive at the attenuation time series as:

$$A(t) = K_A R^\alpha A(t) L_A + r^\alpha K_B R^\alpha B(t) (L_B - L_A)$$  \hspace{1cm} (8)$$

$R(t) = \text{rain rate time series}$

4. Results and Data analyses

![Figure 1: Variation of rainfall rates from 7/1/2020 to 7/31/2020](image-url)
Figure 2: Variation of attenuation due to rainfall by SST from 7/1/2020 to 31/7/2020

Figure 3: SST vs. measured attenuation for rainy events from 7/1/2020 to 7/31/2020
5. Discussion
From 1\textsuperscript{st} June to 31\textsuperscript{st} July 2020, rain events have been monitored and recorded using a rain gauge at 9.91\degree N, 8.88\degree E. The rain events have been converted to an attenuation time series using the SST model as described in equation (2). Estimation of attenuation due to rain by the SST model has been calculated in two separate setups: first is due to rainy layer and second is due to the melting layer. Radio path lengths \( L_A \) and \( L_B \) are estimated according equations (3) and (4). Specific attenuation of the melting layer is constructed according to equation (5) while the values for the coefficients \( k \) and \( \alpha \) are taken as 0.02386 and 1.1825 respectively as given by the ITU recommendations in (5). The average accumulation of rainfall for the period under observation is shown in Figures 1 and 4. From the Figures, we can see that monthly rainfall is dependent on movement of the Inter Tropical Discontinuity (ITD). The Nigerian weather (how can you justify this assertion? Does this cover the whole of Nigeria?) is characterized by two seasons: The dry
and wet season. The dry season is generally from November to March while the wet or rainy season ranges from March till October of the year. April and May are usually characterized with scattered rain patterns due transition from the dry to wet season. From average monthly rainfall accumulations and rainfall databases across the country, we can conclude that worst months are usually June, July and August. Attenuation studies for these months are important for determining the quality of service level possible for telecommunications systems operating in this region. The Figures (2) and (5) for rain events under the period of observation suggests strong correlation between the rainfall rate and corresponding predicted attenuation. The slight variation shown by the rainfall rates and corresponding predicted attenuation values by SST is due to misalignment and small calibration errors across measuring devices. The highest peak value of predicted rain attenuation by SST is 6.92 dB while for the measured attenuation it is 8.3 dB. From Figure (3,) we can see that for 7/1/2020, the SST and measured attenuation values correspond with each other. However, the SST model begins to overestimate the attenuation for at least 5 days. From 7/11/2020 to 7/31/2020 we can observe that the SST model for the most periods underestimates the attenuation due to rainfall although with differences ranging from 2-4 dB. Generally, the SST model performance was satisfactory for the period of observation.

6. Conclusion
This study highlighted the performance of the SST model in Nigerian climate. The model has been established as an accurate method for the prediction or attenuation due to rainfall in most parts of Europe. The SST model is used to generate a rain attenuation time series by using the rain rate data measured for two months in Nigeria for worst month’s case scenario. The time series generated by the SST model is compared with actual measurements conducted on 12.519GHz from NIGCOMSAT-1R. It was found that attenuation predictions from the SST model are consistent with measured rainfall rates for the station under study and across the entire period of measurement. Long term measurements are however still required to arrive at more concrete findings.

References
[1] Matricciani, E. and Riva, C. 2005. The Search for the Most Reliable Long Term Rain Attenuation CDF of a Slant Path and the Impact on Prediction Models. IEEE Transactions on Antennas and Propagation. 53, 3075-3079.
[2] Kanellopoulos, S.A., Panagopoulos, A.D., Matricciani, E. and Kanellopoulos, J.D. 2006. Annual and Diurnal Slant Path Rain Attenuation Statistics in Athens Obtained with the Synthetic Storm Technique. IEEE Transactions on Antennas and Propagation. 54, 2357-2363.
[3] Drufuca, G. 1974. Rain Attenuation Statistics for Frequencies above 10 GHz from Rain Gauge Observations. Journal of Geophysical Research: Atmospheres. 1(2), 399-411.
[4] Yin, X., Ling, C., Kim, M.D., 2015. Experimental multipath-cluster characteristics of 28-GHz propagation channel. IEEE Access. 3, 3138–3150.
[5] Yin, X., Ji, Y., Yan, H., 2017. Measurement-based characterization of 15 GHz propagation channels in a laboratory environment. IEEE Access 5, 1428–1438.
[6] Yun, Z., Iskander, M.F., 2015. Ray tracing for radio propagation modeling: Principles and applications. IEEE Access 3, 1089–1100.
[7] Aviles, J.C., Kouki, A., 2016. Exploiting site-specific propagation characteristics in directional search at 28 GHz. *IEEE Access* 4, 3894–3906.
[8] Maggiori, D., 1981. Computed transmission through rain in the 1–400 GHz frequency range for spherical and elliptical drops and any polarization. *AlFr* 50, 262-273.
[9] Olsen, R.L., Rogers, D.V. and Hodge, D.B. 1978. The $aR^b$ relation in the calculation of rain attenuation, *IEEE Trans. Antennas Propagation*. 26, 318-329.
[10] Houze,R. A. 1981. Structures of atmospheric precipitation systems: A global survey, *Radio Sci.* 16, 671-689.