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Performance Evaluation and Analysis of Cloud Attenuation Prediction Models for Satellite Transmission Quality Improvement

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Abstract

The reliability of social and business interactions on communication infrastructure determines the technological advancement of a nation. In the disclaimer notices of our financial institution's transaction forms, they declared that they are not liable for communication channels malfunction that may lead to transaction interruption, transmission blackout and delayed services. Thus, effective hydrometeors attenuation margins are needed from accurate models to have reliable signal transmissions. Earlier research works established that increase in transmission frequency is directly proportional to attenuation on the signal, and that satellite communication unavailability in most tropical regions is above the allowed 1% outage percentage, significantly due to cloud attenuation contribution at satellite bands. The existence of clouds in tropical climates is almost perpetual, making cloud models all the more fundamental in tropical regions – which include Africa and about half of the rest of the world. The published new tropical cloud attenuation algorithm and its accompanying new tropical cloud attenuation model (NTM) - derived from it, is hereby further analysed with respect to wider frequency range. In the primary research to this work, data were collected from spectrum analyzer, weather-link and radiosonde equipment. The data were used to calculate values of projected attenuation by each major existing cloud model in the propagation range of 12 to 50 GHz. The predicted cloud attenuation values were spectrally processed and analysed. These results in the observation that the NTM's predictions generally average the characteristics prediction values of existing models as shown by the graphical outputs. Also, the predicted attenuation values by each of the cloud models converge increasingly with frequency.

Keywords: Satellite signals, Frequency, Transmission quality, Attenuation margin, New cloud algorithm, New cloud model

1.0 Introduction

Clouds are the various forms of condensation of water vapour on aerosols, at various geopotential heights, temperature and pressure in the atmosphere. Aerosols are gaseous particles, including man made activities - produced tiny particles, such as those produced by exhaust systems, burning of oil or coal or forest and dusts of deserts blown by wind. Change in aerosol type has been observed to results in cloud type change, precipitation amounts and consequently - climate change (Eva et al., 2015). Thus, clouds types' formation is based on various atmospheric conditions at the heights in the presence of lifting mechanism such as orographic lifts and convection. An unstable air area of the atmosphere has a higher temperature than its surrounding air areas, which causes the unstable air mass to rise. While rising, more water condenses on the cloud nuclei and it grows into cloud droplets of higher sizes until it is saturated. Hence, subsequent condensation of water on it falls off as precipitation (Luini and Quadri, 2018). Water vapour and hygroscopic aerosols rises in the Earth's atmosphere from its land surface. The temperature fall and rise occurs between troposphere and adjacent stratosphere, and also between mesosphere and adjacent thermosphere. These temperature range alternations has condensation effects on the cloud nuclei in these regions and clouds are found majorly in the regions.

The cloud layers protect life and materials on the Earth surface from adverse effects such as burning and other harsh effects of the weather of space environment. However, the hydrometeors such as clouds, rain and gases affect signal transmissions mainly through absorption of propagation energy. It has been established by previous research that hydrometeors not only absorb signals energy, but also polarize the signals and cause other propagation impairments such as scattering and scintillation (Luini and Quadri, 2018; Lyras, Kourogiorgas and Panagopoulos, 2018). Thus, clouds – which are most often in motion and hence randomly located in the atmosphere, degrade electromagnetic signal and absorbs its energy by amounts proportional to the amount of liquid water content of each cloud body it encounters along the signal propagation path. Of the ten existing cloud types, eight often occur in non-rainy weather and contains averagely lower amount of liquid water, namely Cumulus (C), Stratus (St), Stratocumulus (Sc), Altocumulus (Ac), Altostratus (As), Cirrus (Ci), Cirrocumulus (Cc), Cirrostratus (Cs), while the other two are associated with rain and contains averagely higher amount of liquid water namely, Cumulonimbus (Cb) and Nimbostratus (Ns) (Warren, Hahn and Eastman, 2007).

Communication satellites are designed to relay radio transmissions between earth terminals or stations to facilitate communication of data, voice and video through multimedia systems, very rapidly, for scientific, economic, social, educational and general purposes. Hence, signals transmission by wireless methods requires additional power margin to burn through hydrometeors in the atmosphere. Satellite propagation phenomena uses statistical channel modelling through appropriate statistical distribution (Giovanni, 2007). These were employed by almost all the pioneer cloud attenuation models. The tropical lower atmosphere is more often cloudier than temperate regions (Ojo, 2017; Omotosho, Mandeep and Mardina, 2011). Adewusi et al. (2019) analytically developed and published a new cloud attenuation algorithm - Equation (1), modified to accommodate empirical data and also, the new tropical cloud attenuation model (NTM) - Equation (2), derived from it. The new cloud algorithm and NTM were further established through published climatic data analyses bases (Adewusi et al., 2021).

2.0 Experimental Method

This experiment was designed and conducted to measure and log total attenuation along earth – space path from Ota (6.67oN, 3.23oE) southwest, Nigeria to Astra satellite and measure cloud cover for the station using spectrum analyzer, weather link and digital camera respectively. Figure 1 shows the setup diagram. Measurement of the total hydrometeor attenuation along earth – space path at the Ota station were carried out with spectrum analyzer, by propagating beacons at elevation angle 59.9o to Astra satellites. The weather link and digital camera were used to measure weather parameters, while radiosonde data for fifty-eight years were acquired for the station. Measurement details and their data processing were published (Adewusi et al., 2019). The processing includes extraction of the cloud attenuation contribution from the measured and logged total attenuation.

The developed and published cloud attenuation algorithm - Equation (1), (Adewusi et al., 2019) is:

$$A_c = A_o W_L \cos((0.5K_L) + B) \quad 0 \le K_L \le \pi \qquad (1)$$

Here, Ac, Ao and B represents the cloud attenuation (dB) in given cloud layer(s), the amplitude and phase constant of the propagating beacon signal respectfully. Also, W_L and K_L represent liquid water content of the cloud layer(s) and specific attenuation coefficient as defined by the ITU-R. The attenuation algorithm can be used to derive specific cloud attenuation model for any climatic area or region as explained in earlier publication (Adewusi et al., 2019). Briefly, this require using written simulation program such as presented in Appendix A – for deriving the variable constants - Ao and B , while climatic parameters W_L and K_L are obtainable from local radiosonde data, as applied in deriving the published tropical southwest Nigeria cloud attenuation model (NTM) - Equation (2), (Adewusi et al., 2019).

$$A_c = 11.5 W_L \cos((0.5K_L) + 1.560796) \quad 0 \le K_L \le \pi \qquad (2)$$

Equation (2) imply the simulation produced at 11.5µm and 1.560796 of the randomly chosen values for A_o and B respectively has closest match to the station area's cloud attenuation cumulative distribution curve at 12.245 GHz.

Current analysis was carried out at broad range values of 12 to 50 GHz. Projected cloud attenuation of each existing cloud models and NTM were computed. Then their respective cumulative distribution curves were compared per frequency by placing them in common axes.

3.0 Results and Discussion

Cumulative distribution curves of the predicted cloud attenuation by respective cloud models at indicated frequency are compared in the following Figures 2 – 7. Figures 2 and 3 shows NTM predictions shortly coincide with the ITU-R model at about peak exceedance, beyond which it extensively diverges and predict higher attenuation for the downlink and uplink in the Ku band. The behaviour is consistent relative to other models, however, at 14 GHz some predictions convergence occurred. Figures 4 and 5 shows NTM predictions shortly coincide again with the ITU-R model at about peak exceedance, beyond which it extensively diverges and predict higher attenuation for the downlink and uplink in the Ka band. The behaviour is consistent relative to other models, however, at 30 GHz higher predictions convergence occurred. Specifically, at 20 GHz, only Gun and East model has lower predictions relative to the ITU-R model. However, at 30 GHz, NTM and models has higher predictions relative to the ITU-R model. Figures 6 and 7 shows NTM predictions shortly coincide with the ITU-R model at about peak exceedance, beyond which it extensively diverges and predict higher attenuation for the downlink and uplink in the V band. The behaviour is consistent among other models and high prediction convergence occurred. Predictions convergence by the cloud models is greatest at 50 GHz. Table 1 shows statistical attributes of the various projected cloud attenuation values of the cloud models. The average predicted cloud attenuation values of the models in the frequency range were calculated and shown on the table.

NT model predictions were consistently highest for Ku and Ka bands, but Slobin model predictions were highest in the V – band. Blue colour indicate lowest cloud attenuation prediction, while red colour indicate highest cloud attenuation prediction in each frequency, including the corresponding model that produced each of them. The computed average values relative to each cloud attenuation prediction values shows consistent convergence as the frequency increases.

4.0 Conclusion and Recommendation

The bad experience on Ku and Ka band transmission in some tropical areas is most fundamentally due to application of very low attenuations margins predicted by earlier models which are fabricated in non – tropical areas, based on their different climatic initial and

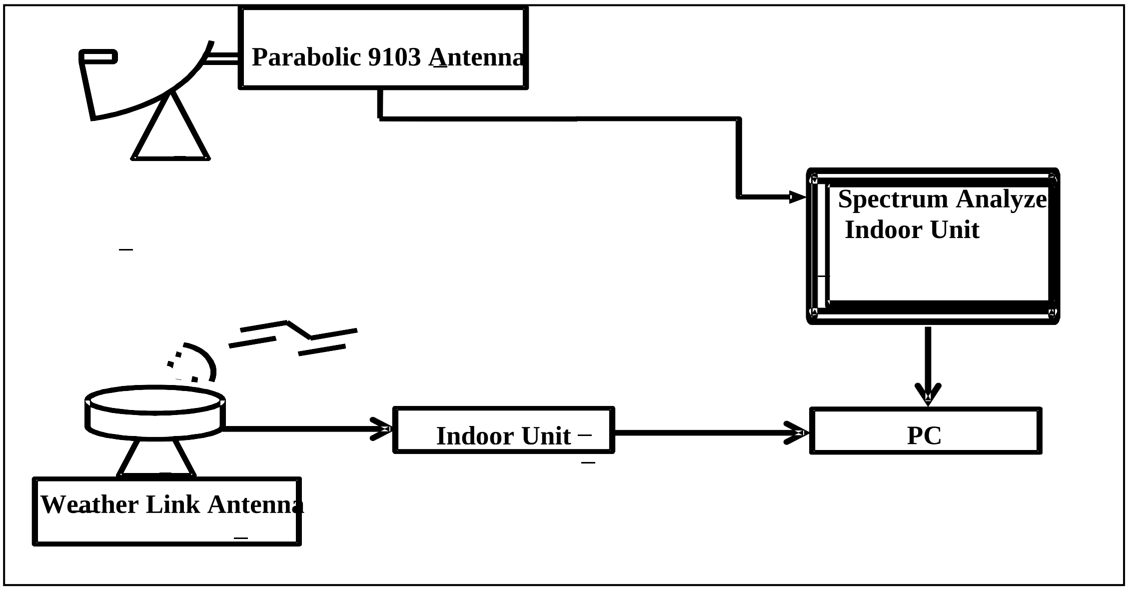

Figure 1: Station Spectrum Analyzer and climatological setup block diagram

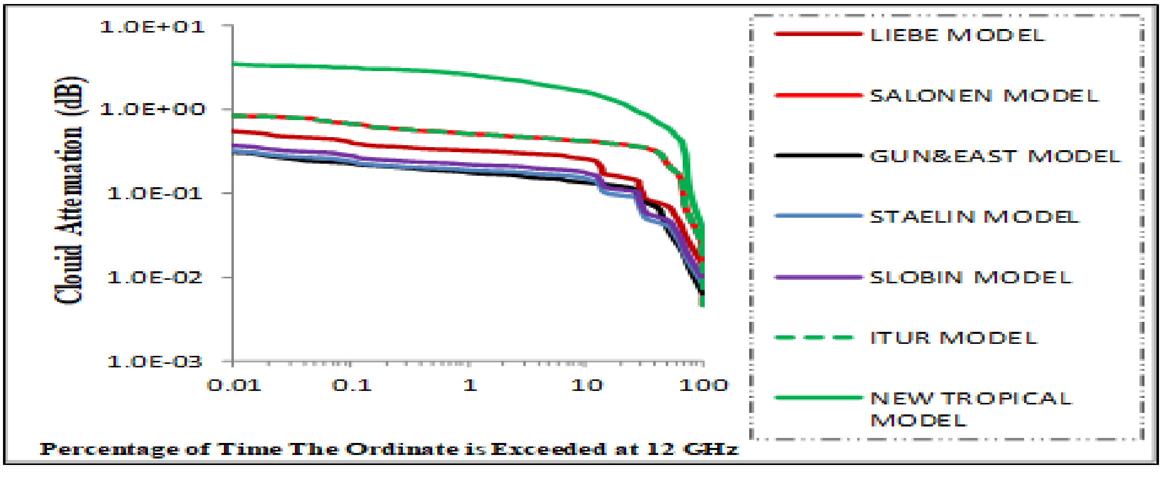

Figure 2: Cumulative distributions of cloud models at 12 GHz

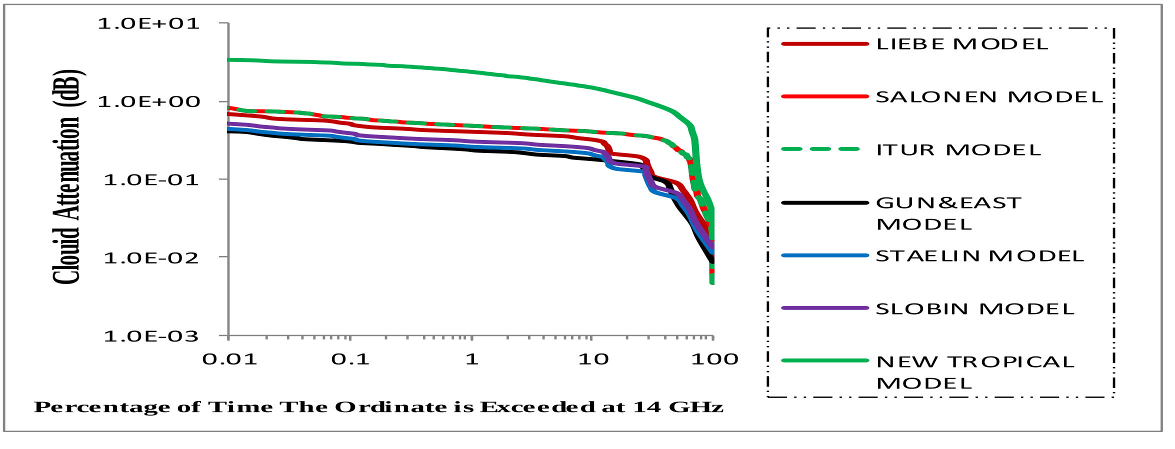

Figure 3: Cumulative distributions of cloud models at 14 GHz

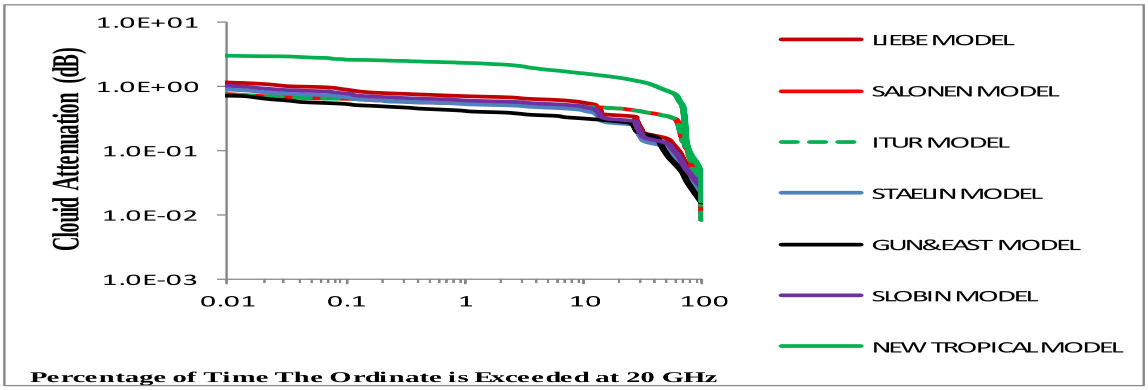

Figure 4: Cumulative distributions of cloud models at 20 GHz

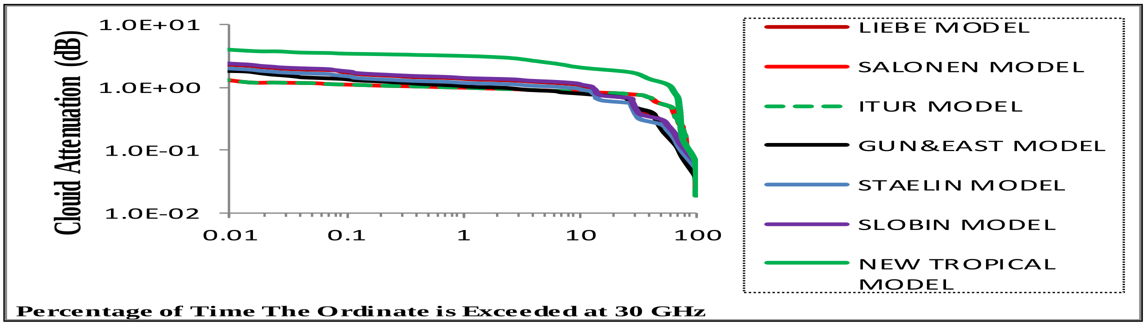

Figure 5: Cumulative distributions of cloud models at 30 GHz

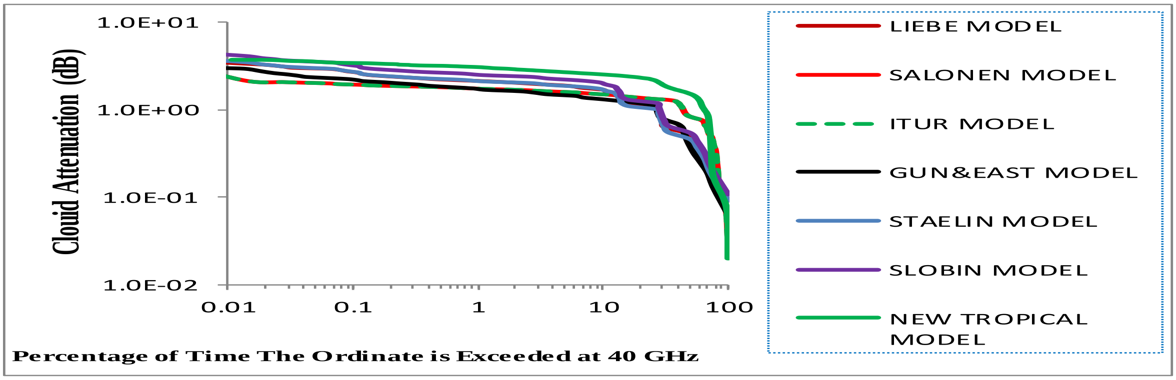

Figure 6: Cumulative distributions of cloud models at 40 GHz

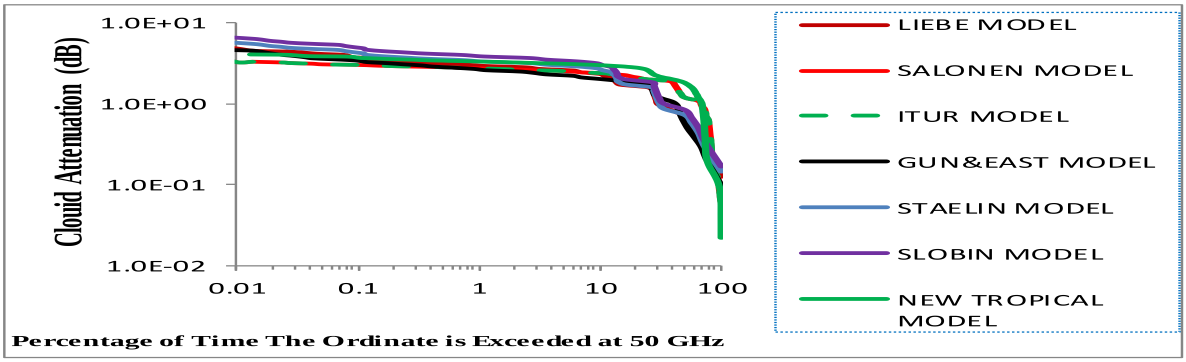

Figure 7: Cumulative distributions of cloud models at 50 GHz

Table 1: Predicted Cloud Attenuation Variation with Frequency

Cloud Model	Ku Band		Ka Band		V Band	
	A14 (dB)	A12 (dB)	A30 (dB)	A20 (dB)	A50 (dB)	A40 (dB)
NT	3.4072	3.625	4.02	3.028	4.1039	3.7775
ITU-R	0.8337	0.8266	1.2113	0.7335	3.3538	3.1127
Gun and East	0.4147	0.3047	1.7816	0.7335	4.489	2.9832
Staelin	0.4284	0.3147	1.9672	0.9663	5.4643	3.8653
Slobin	0.5493	0.4035	2.2819	1.1209	6.339	4.4837
Liebe *et al.*	0.6955	0.5474	2.2819	1.1834	4.9763	3.5102
Average (dB)	**1.0548**	**1.0037**	**2.2573**	**1.2943**	**4.7877**	**3.6221**

boundary conditions. NTM have better performance and its behaviour is consistent in correlation with respect to the overall existing cloud attenuation models average performance observed. Thus, the NTM's predictions generally average the characteristics prediction values of existing models as shown by the graphical outputs. Also, the predicted attenuation values by each of the cloud models converge increasingly with frequency.

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Conflict of Interest

Self-sponsored research with no financial, personal or other relationship with other people or organisation.
Individual Author's Contribution
Conception: Adewusi, O.M., Omotosho T. V., Akinyemi, M. L.
Design: Adewusi, O.M., Omotosho T. V.
Data collection/analyses: Adewusi, O.M., Akinwumi, A O., Ometan, O.
Writing of the Manuscript: Adewusi, O.M.

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Appendix A

Matlab Program For The Cloud Attenuation Algorithm Simulation

```
function Ac = SimulationProgram(WL,KL,A0,B)
% function Ac = SimulationProgram(WL,KL,A0,B)
% Input:    A0 = Amplitude
%               B = Phase
% Output:  Ac = Cloud Attenuation; absolute values.

Ac = abs(A0*WL.*cos((0.5*KL) + B));
Lk = length(KL);
for i = 1:Lk
if KL(i)>pi
Ac(i)=0;
end
end
```