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Predictions of cloud attenuation models for uplink and downlink margins at ku, ka and v bands in tropical regions

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Abstract. To achieve effective wireless transmission margin and larger bandwidth at lower cost, hydrometeor models roles are of primary importance. The almost perpetual existence of clouds in tropical climates makes cloud models all the more fundamental. Details of four years station spectrum analyzer data, five years climatological data and fifty – eight years radiosonde data used in this research were earlier published. The radiosonde data was used to obtain existing primary cloud models' predicted cloud attenuation cumulative distributions for the station and it was also used to deduce the new algorithm's parameters for the station. The every minute measured and logged station cloud attenuation data using spectrum analyzer was used to deduce the station cloud attenuation cumulative distribution for comparison with that of other existing cloud models. The simulation program was run to generate the new cloud attenuation algorithm's parameters, which defines the cloud attenuation model for the station. Thus the new model only fundamentally requires station radiosonde data. The cloud cover data and all others are needed only for graphical comparisons and corroboration. Thus the new tropical cloud attenuation algorithm can be used to develop the cloud attenuation model for any station climatic zone by using the methodology earlier published. Collected spectrum analyzer data, climatological data and acquired radiosonde data were used to compute projected attenuation values for each cloud attenuation model at propagation signal frequencies between 12 GHz to 50 GHz. The predicted values were extracted and analysed statistically. With respect to frequency, the new cloud attenuation model's cumulative distribution proportionally averaged the characteristics of the cumulative distributions deduced from the station radiosonde data and that of the spectrum analyzer data as shown by the graphical figures. The results show that convergence of the range of predicted attenuation values by each of the cloud models increases directly with frequency.

Keywords: Satellite Transmission, Cloud Attenuation Margins, Signal Frequency, Cloud Models, New Cloud Algorithm, New Cloud Model.

1. Introduction

Earth atmosphere's hydrometeors constitute a protection for life and materials on Earth, from burning and other adverse effects of extreme temperatures due to the Sun. However, the hydrometeors cause substantial radiowave attenuation, particularly satellite communication signal attenuation through absorption. Previous studies established that hydrometeors absorbs electromagnetic signals energy, polarize the signals and cause other radio wave propagation impairments as scattering and scintillation effects, while the signals are on transmission to and fro between various locations on Earth and space. Above the stratosphere, frequencies below 3 GHz experiences very high ionospheric scintillation, though the effect degenerates as the frequency increases. Also, for frequencies above 10 GHz, rain and clouds impact critically on propagating signals, followed by gases as oxygen and water vapour [1, 2]. Clouds mainly exist in the troposphere. It extends up to about 8 km in the polar region and up to about 18 km on the equator.The tropical lower atmosphere may be more often cloudier than temperate regions [3, 4]. This implies standard satellite services performance may be more difficult to achieve ordinarily in the tropical regions. Reference [5] proposed a new tropical cloud attenuation algorithmanalytically developed, but modified to accommodate empirical data and a new tropical cloud attenuation model (NTM) Themodelling process includerepeated comparisonof computed cumulative distribution curves with that of each corresponding simulation distribution to obtain the closest match to determine the numerical values of the algorithms parameters.

The highly effective wireless transmission method necessitate propagating signal to pass through the randomly located cloudsin the atmosphere, but the clouds absorbs the signal energy and proportionally degrade the signal with respect to the amount of liquid water content of the cloud. There exist ten cloud types.Eight of the cloud types 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).The other two cloud types are associated with rainand contains averagely higher amount of liquid water, namely Cumulonimbus (Cb) and Nimbostratus (Ns) [6]. Thus, wireless signals transmission through clouds require additional power margin to burn through them. The effects of hydrometeors i.e. water vapour, rain and clouds become more acute for systems operating in the bands above 10 GHz [7]. Reference [8] carried out a similar radiowave propagation experiment at Penang, Malaysia. Their results show the specific attenuation of radio wave due to clouds at frequencies between 12 GHz to 100 GHz range between 0.14 dB/km at 12 GHz to 10.1 dB/km at 100 GHz. These results indicated that the models that applied the retrieved cloud liquid water content have better predictions relative to those that usedclimatological parameters. Though modelling of communication channel follows either a deterministic approach or a statistical approach, however, application of the deterministic approach to satellite systems has been established to be practically unfeasible due to vast area cover associated with satellite beam. Thus statistical channel models are employed in modelling relevant satellite propagation phenomena such as signal diffraction, absorption and scattering through appropriate statistical distribution [9]. This could be observed in almost all the pioneer cloud attenuation models, hence satellite propagation phenomena models are mainly empirical and follows the statistical approach. Thus, attenuation models may be described as experimentally based algorithm, scientifically designed to predict attenuation magnitude on wireless signals.

2. Methodology

The details of beacons total attenuation measurements along defined atmospheric path to the Astra satellites at 12.245 GHz; the acquired radiosonde data (1953 – 2011) and their processing were published [5]. The processing particularly focused at extractingfrom the total attenuation measured the cloud attenuation contribution using each cloud attenuation models.

Reference [5] developed and published algorithm for computing attenuation due to cloud - Equation (1):

$$Ac = Ao\, W_L COS\,((0.5K_L) + B) \quad 0 \leq K_L \leq \pi \quad (1)$$

Where Ac is the cloud attenuation (dB) in cloud layers, Ao and B are respectfully the amplitude and phase constant of the propagating signal through the cloud layers, whose liquid water content is W_L and K_L is its specific attenuation coefficient as defined by the ITU-R. Equation (1) can be used to derive the specific cloud attenuation model for a climatic area or region using the simulation program presented in Appendix 1. The simulation program was applied in deriving the proposed cloud attenuation model for tropical Ota, southwest Nigeria, presented as Equation (2):

$$Ac = 11.5\, W_L\, COS\,((0.5K_L) + 1.560796) \quad 0 \leq K_L \leq \pi \quad (2)$$

which indicate that the simulations produced the closest match to the area station integrated cloud attenuation cumulative distribution at 11.5 and 1.560796 for A_o and B respectively.The computations in the programmed spreadsheets for the [5] publication was at beacons measurement frequency of 12.245 GHz. Now, the computations in the spreadsheets are extended by setting the propagation frequency to projected values between 12 GHz and 50 GHz. The computations were carried out at intervals of uplink and downlink for Ku, Ka and V – bands. At each frequency, the projected cloud attenuation by each of the cloud models algorithm are computed. The cloud attenuation cumulative distribution curves for each of the cloud models are placed in the same axes for comparison. The projected cloud attenuation variation with frequency at 0.01% exceedances for each of the cloud models are tabulated also for comparison.

3. Results and Discussion

The cloud attenuation cumulative distribution curves at time exceedance of 0.01% for each of the cloud models are shown by Figures 1 – 6.

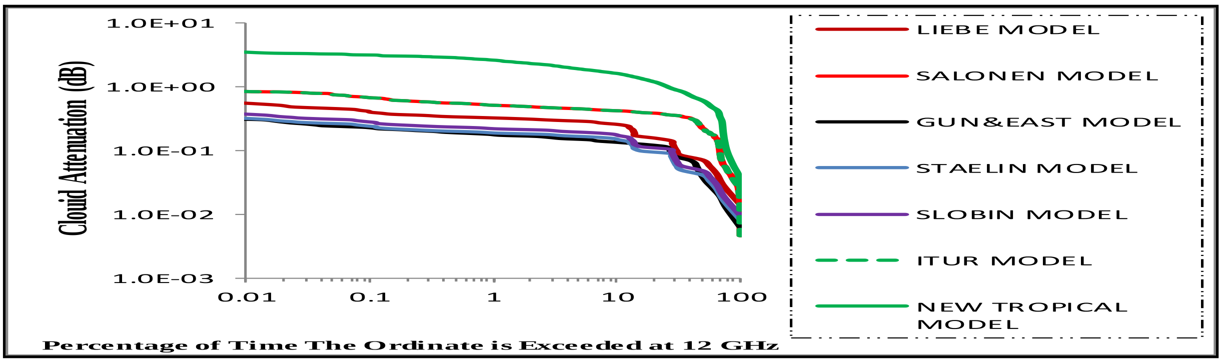

Figure 1: The cloud models cumulative distributions at 12 GHz

In the Ku band the cumulative distribution for the downlink and uplink are shown by the Figures 1 and 2.

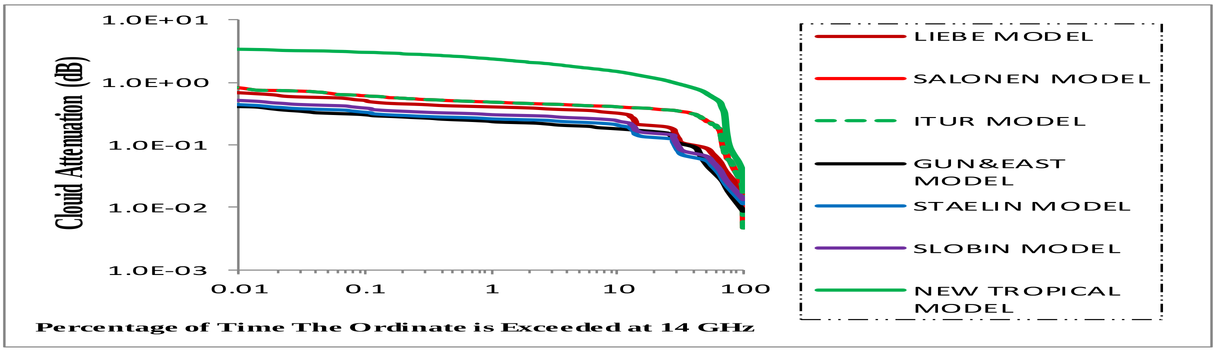

Figure 2: The cloud models cumulative distributions at 14 GHz

Figures 1 and 2 shows the new tropical (NT) model almost coincide with the ITU-R model up to about 73.63 dB, beyond which the NT model predicts higher attenuation. In the Ka band the cumulative distribution for the downlink and uplink are shown by the Figures 3 and 4. The Figures 3 and 4 shows the new tropical (NT) model almost coincide with the ITU-R model up to about 72.40 dB, beyond which the NT model predicts higher attenuation.

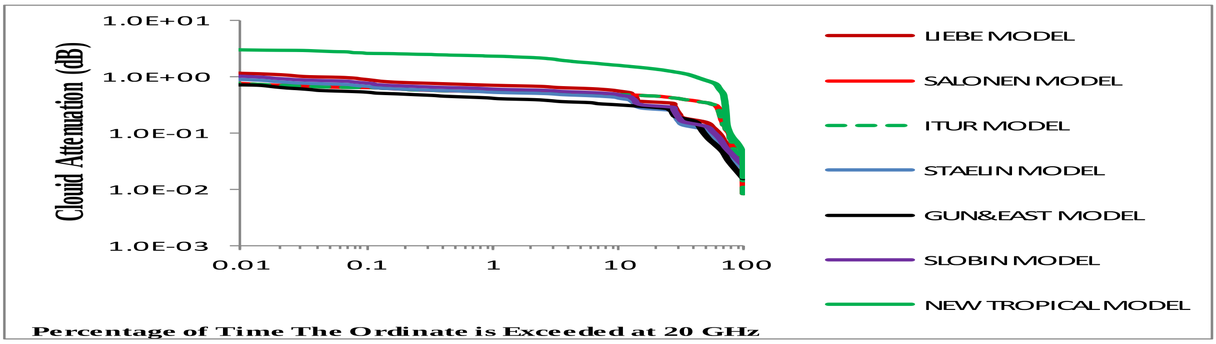

Figure 3: The cloud models cumulative distributions at 20 GHz

At 20 GHz, only Gun and East model has lower attenuation profile relative to the ITU-R model, while all other cloud models has higher predicted attenuation profile relative to the ITU-R model at 30 GHz.

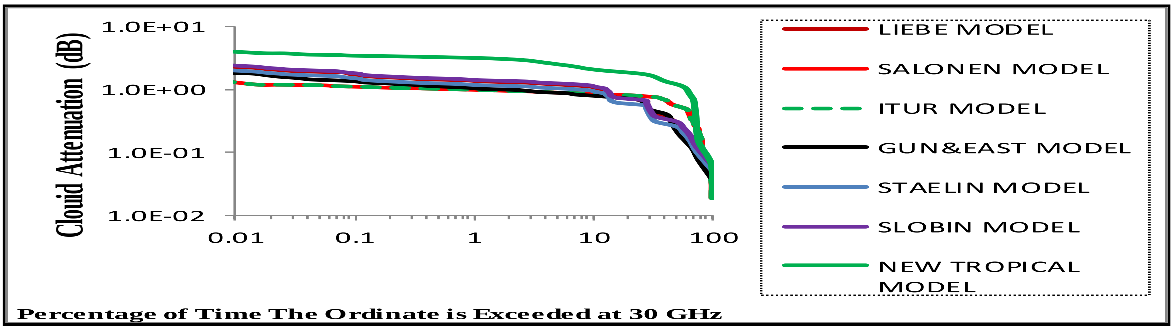

Figure 4: The cloud models cumulative distributions at 30 GHz

Also, the gaps between their range of predicted values reduced substantially in convergence.In the V band the cumulative distribution for the downlink and uplink are shown by the Figures 5 and 6:

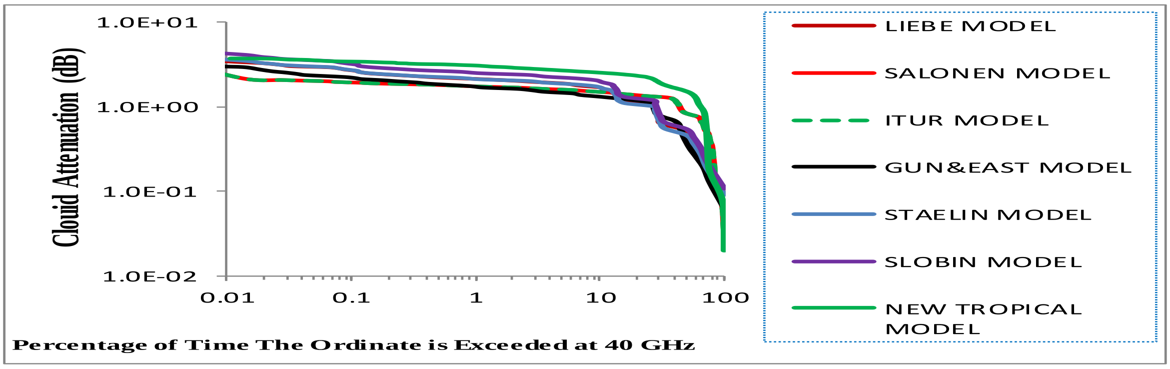

Figure 5: The cloud models cumulative distributions at 40 GHz

The Figure 5 shows the trend at 30 GHz continue i.e. all other cloud models has higher predicted attenuation profile relative to the ITU-R model at 40 GHz, and Staelin model overtake NT model having predicted the highest maximum cloud attenuation. Furthermore, Figure 6 shows the trend at 30 GHz continue i.e. all other cloud models has higher predicted attenuation profile relative to the ITU-R model at 50 GHz, and Slobin model overtake NT model having predicted the highest maximum cloud attenuation. The convergence of all the cloud models is highest at 50 GHz.

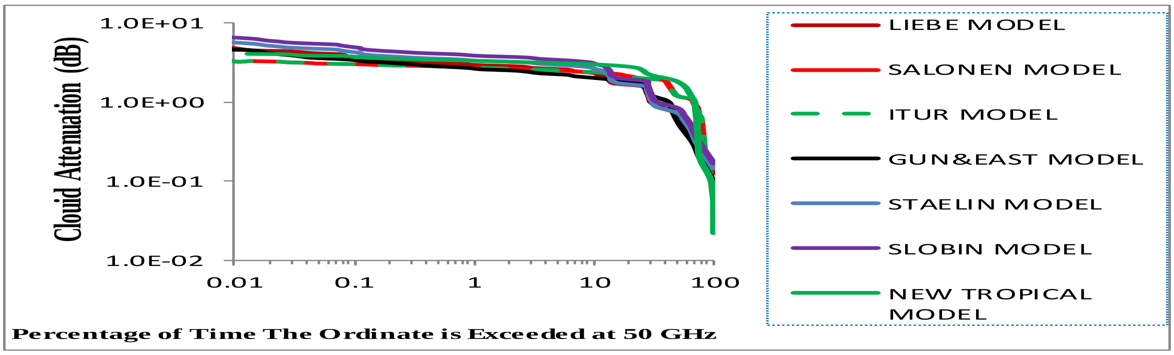

Figure 6: The cloud models cumulative distributions at 50 GHz

Table 1 shows projected cloud attenuation variation with frequency at 0.01% exceedances for each of the cloud models. The frequencies computed are the uplink and downlink frequencies for Ku, Ka, and V – bands respectively for each of the cloud models. The NT model predicted maximum cloud attenuation for both uplink and downlink at Ku and Ka – bands, while Slobin model predicted maximum cloud attenuation for both uplink and downlink at V – band. The Gun and East model predicted lowest cloud attenuation for both uplink and downlink at Ku band, while the ITU-R model predicted lowest cloud attenuation for both uplink and downlink at Ka band.

Table 1: Projected Cloud Attenuation Variation with Frequency at 0.01% Exceedances

S/N	Cloud	Ku Band		Ka Band		V Band	
	Model	A_{14} (dB)	A_{12} (dB)	A_{30} (dB)	A_{20} (dB)	A_{50} (dB)	A_{40} (dB)
1	Gun & East	0.4147	0.3047	1.7816	0.7335	4.489	2.9832
2	Staelin	0.4284	0.3147	1.9672	0.9663	5.4643	3.8653
3	Slobin	0.5493	0.4035	2.2819	1.1209	6.339	4.4837
4	Liebe *et al.*	0.6955	0.5474	2.2819	1.1834	4.9763	3.5102
5	ITU-R	0.8337	0.8266	1.2113	0.7335	3.3538	3.1127
6	NT	3.4072	3.625	4.02	3.028	4.1039	3.7775
Average		**1.0548**	**1.00365**	**2.257317**	**1.294267**	**4.787717**	**3.6221**

At the V – band the ITU-R model predicted lowest cloud attenuation for only uplink while Gun and East model predicted lowest cloud attenuation for only the downlink. At the Ka – band the ITU-R and Gun and East models coincide to predicted lowest cloud attenuation for only the downlink. The Gun and East model predicted lowest cloud attenuation for only the downlink at V - band. The average cloud attenuation predicted for uplink is consistently higher than those predicted for down at Ku, Ka, and V – bands respectively.

4. Conclusion and Recommendation

With respect to frequency, the resulting new cloud attenuation model's cumulative distribution proportionally averaged the characteristics of the cumulative distributions deduced from the station radiosonde data and that of the spectrum analyzer data as shown by Figures 1 - 6. Hence, the new tropical cloud attenuation algorithm can be used to develop the cloud attenuation model for any station climatic zone by using the methodology earlier described [5].Thus, the convergence of the range of predicted values by each of the cloud models increases directly with frequency, i.e. they are closer in their predicted attenuation values as the frequency increases from 12 GHz to 50 GHz. The behaviour of the new model exhibits better performance and consistent correlation with respect to the primary cloud attenuation models.

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Appendix 1

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
```