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# Advancement on Cloud Attenuation Modelling in Tropical Ota Climatic Zone

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**Abstract.** This is a further study on development of the cloud attenuation model for improvement of the availability of satellite services in tropical Ota (6.7oN, 3.23oE) climatic zone. The radiometric data analysis has been re-evaluated for better accuracy through the Matlab embedded into the data processing electronic spreadsheets. The collection of station data such as the spectrum analyser beacon measurements of the total attenuation at re-established elevation angle 59.9° to Astra 2(E-G) satellites located at 28.2°E; the station weather parameters and the clouds parameters visual measurements; as well as the acquisition of station climatic zone radiosonde data were carried out. Then the station spectrum analyser data for 2014 - 2017 were analysed to obtain cloud attenuation contributions from the total attenuation measurement. Cloud attenuation distributions outputs of these data analyses were used to obtain the station integrated cumulative distribution for each of the existing cloud models and the 2014 – 2017 integrated data. The results at the station beacons frequency of 12.245 GHz show wide gap between the 3.40 dB maximum cloud attenuation by the Ota spectrum analyser integrated data cumulative distribution to the 0.81 dB maximum cloud attenuation predicted by its closest ITU-R model, while next in closeness is the Liebe model, followed by Slobin model. This recommends a new cloud attenuation model be developed for the tropical region. The earlier published cloud attenuation algorithm is further developed with simulation program written to run its simulations cycles over possible range of maximum signal amplitudes, using the Ota climatic zone radiosonde empirical data (1953-2011) for computations of each cloud layer's liquid water content and specific cloud attenuation coefficient. The cumulative distribution curves obtained were compared with those for each generated simulation distribution and the closest match to the station integrated data cumulative distribution became the new cloud attenuation model for Ota climatic zone. The new model predicted 4.0 dB margin for signals to pass through clouds attenuation effect in the Ota climatic zone, revealing that the prediction for cloud attenuation by the earlier models largely under estimate the margin for the tropical region.

## Introduction

The Earth is surrounded by varying amounts of precipitations, clouds, gases and water vapour at various temperatures and heights in its atmosphere with respect to time. Clouds are the various forms of condensation of water vapour on aerosols, both of which rises from Earth surface. Aerosols are atmospheric suspended particles as gases and tiny particles produced by ignition engine exhaust systems and other man made activities involving burning of coal and oil; forest fire and wind-blown desert dusts. Clouds consist of visible aggregates of less than 0.1 mm diameter tiny water droplets, and often include very tiny crystals of ice particles. Temperature falls and rises in the vertical plane of the atmosphere. The first temperature fall occurs in the troposphere and rises in the adjacent stratosphere, while the second temperature fall occurs in the mesosphere and rises again in the adjacent thermosphere [12]. Each of the two falls has condensation effects on the atmospheric matters in the



named regions and clouds are found majorly in these two regions. Thus clouds are formed by condensation of water vapour on hygroscopic aerosols, which results in formation of cloud condensation nuclei (CCN) when atmosphere is unstable and appropriate lifting mechanism such as convection, convergence, frontal and orographic lifts exist appropriately. As the cloud nuclei rises, more water condenses on it and the cloud droplets grow in size until it is saturated and subsequent water vapour condensation falls off the saturated cloud droplets as precipitation. Thus rain can be due to the growth of cloud liquid water density in a given cloud type. It has been observed that changes in aerosol type relate to changes in cloud type formed, precipitation and hence climate change. Stability of the atmosphere depends on the moisture content of the air. It is stable when air is dry and unstable when air is saturated [1 - 3].

The ten common cloud types are classified into low, middle and high clouds i.e. clouds having their base at the atmospheric height < 2 km above the earth surface such as cumulus (Cu), stratus (St) and stratocumulus (Sc), nimbostratus (Ns), and cumulonimbus (Cb); clouds having their base between 2 km and 6 km above the surface of the earth such as altostratus (As) and altocumulus (Ac); and clouds having their base between 6 km and the tropopause such as cirrus (Ci), cirrocumulus (Cc), and cirrostratus (Cs) respectively. It has been observed that clouds above the tropopause are rare, but do occur between 15 km to 25 km heights, as polar stratospheric clouds; and in the mesosphere at 80 km height as 'polar mesospheric' clouds. Though cumulus (Cu) clouds are bumpy and relatively small, however they can grow into large cumulonimbus (Cb), which is a cloud that may vertically develop to tropopause and are accompanied by lightning, thunder and precipitations. Also stratus (St) and stratocumulus (Sc) are both horizontally extensive low clouds covering large regions of the ocean, and they are distinguished by the fact that stratocumulus includes convective elements but stratus does not. Nimbostratus (Ns) cloud is much thicker than stratocumulus and stratus [1, 4].

The degree of response and reliability obtainable from public and private institutions measures the degree of progress of the populace, and these are related to the degree of efficiency of existing communication channels available. Hence the existing relatively high percentage of satellite communication unavailability in tropical Ota climatic zone need be overcome by obtaining required effective models through consistent collection and analyses of relevant radiometric and climatological data. Earlier publication reported the Ota station ground (visual) and satellite cloud cover data collection and analysis [5].

### **1. The Station Cloud Cover Data Analysis Result**

The station cloud cover data involve the average cloud amount per month for all the periods of data analysed in visual cloud observation segment, as well as the satellite data segment. They were extracted, assembled and compared in Table 1. The table enable computation of the correlation between the satellites data and ground data; it shows a positive correlation of 0.7882 i.e. approximately 0.8 exists between the mean monthly cloud amount values for all the satellites data relative to the mean monthly cloud amounts (%) data observed in the station visual measurements. The table indicate that the accuracy of the visual data observed at the station is 64.3% relative to all the satellites monthly mean, and 93.9% relative to CALIPSO satellite monthly mean. The range of vertical heights occupied by the three cloud classes in the tropospheric layer of the atmosphere on Ota climatic zone is described by Figure 1 and it indicates average of 3 km vertical height difference between the average heights of the low clouds, middle clouds and the two plates (P1 and P2) of the high clouds – based on the CERESTerra-Aqua-MODIS satellites clouds base heights data (2000 – 2015) for Ota climatic zone. Figure 2 shows a comparison between the SRB satellite daily cloud amount data and the corresponding visual daily cloud amount data observed at the station. The common low cloud types over Ota are stratus, stratocumulus and cumulus; while Nimbostratus occur about 20% of the time, Cumulonimbus occur only occasionally, hence Ota weather will most often than not be bright for most part of a year, thus the environment is largely conducive for social activities as educational, businesses, entertainment etc.

Table 1: Ota visual and satellites clouds amount (%) means comparison

	Satellites Monthly Average Cloud Amount							Visual Data (VD) Mean
	CloudSat	SRB	ISCCP	CERES	CALIPSCC	T-A-M	SATs. MEAN	V.D. MEAN
JAN	15.1606	33.4121	43.6128	49.0370	63.5667	44.6714	41.5768	79.0592
FEB	20.2771	42.2097	51.2332	62.7260	76.2187	55.7857	51.4084	79.0431
MAR	43.6459	57.9273	68.8875	74.3223	82.6795	65.2335	65.4493	82.0700
APR	44.8604	65.7674	74.0642	78.5329	89.8978	68.6588	70.2969	82.1300
MAY	49.3148	66.7391	71.2498	76.3202	92.9146	69.3566	70.9825	87.6114
JUN	59.0425	70.6840	75.6415	77.7327	87.0072	72.5455	73.7756	89.1871
JUL	55.6049	74.8319	82.1054	79.0880	86.8986	75.1494	75.6130	89.9949
AUG	61.8760	74.2531	82.7596	75.2827	86.8338	71.1376	75.3571	89.8575
SEP	65.8786	75.0585	82.5380	78.1871	88.2813	73.3606	77.2173	90.3499
OCT	44.3849	64.1697	71.9371	73.7686	85.5979	64.6955	67.4256	89.6038
NOV	30.2021	42.9618	50.2785	53.3699	67.8503	46.8935	48.5927	87.4892
DEC	15.2401	32.0395	38.6185	41.4417	56.7292	36.3396	36.7348	77.1806
ANNUAL AVG.	42.1240	58.3378	66.0772	68.3174	80.3730	61.9857	62.8692	85.2981
S.D. ( $\sigma$ )	17.21966	15.61718	15.163	12.69345	11.13203	12.37744	13.73297	4.800921
Variance	296.5168	243.8963	229.9165	161.1237	123.9222	153.201	188.5943	23.04885
Correlation	0.855755	0.823621	0.796515	0.683365	0.678399	0.730773	0.788217	

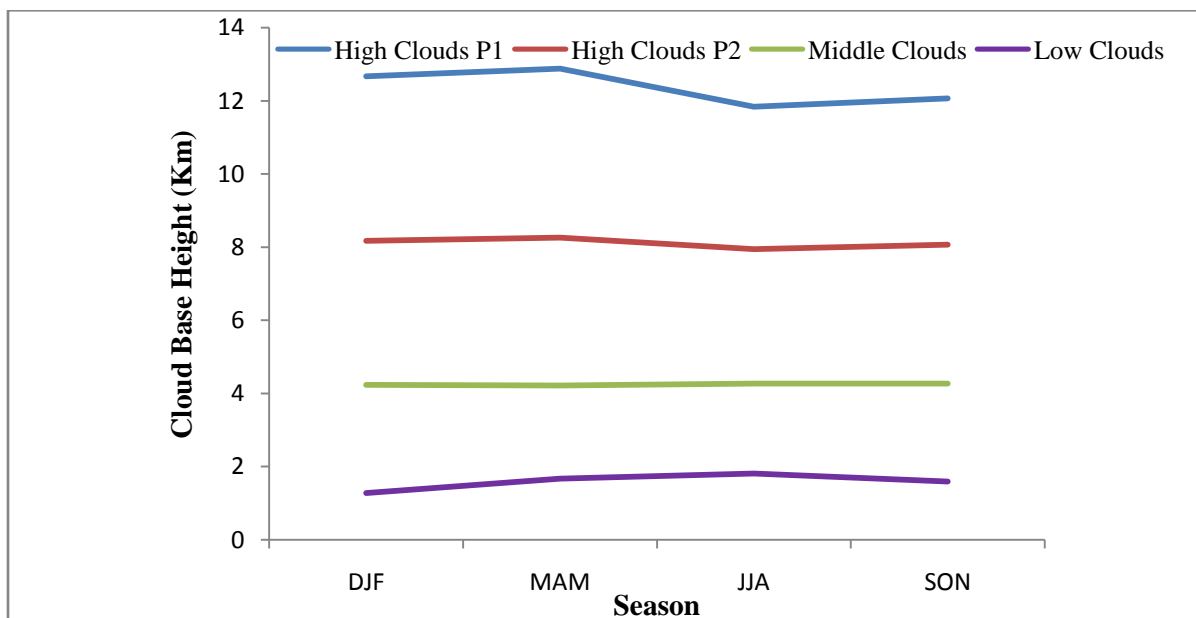


Figure 1: Satellite seasonal cloud base height averages (2000 -2015)

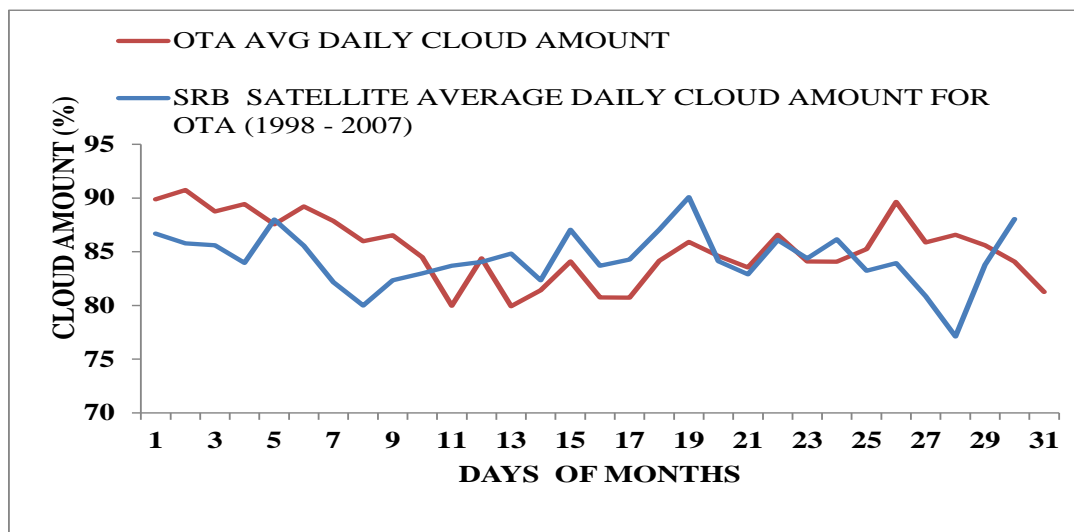


Figure 2: Comparison of Ota visual and satellite daily average cloud amount data

## 2. Radiometric Data Collection and Analysis

Radiometric data for the Ota station includes the acquired radiosonde data and the logged signal attenuation measurements of the spectrum analyzer. The station spectrum analyzer measures the total attenuation every minute on beacons been propagated along the defined earth-space path to the Astra satellites at 12.245 GHz. The station Davis Weather Link climatological device measured and recorded data (2012 – 2017) were also extracted for rain event dates and their corresponding times during the period. The spectrum analyzer data measurements were studied under the two possible local weather conditions i.e. the rainy and non-rainy conditions, where the clear sky and cloudy conditions are considered under non-rainy condition. The cloud attenuation contributions of the total cloud attenuation measurement data of the spectrum analyzer for 2014 – 2017 were computed through written daily probability of cloud occurrence program. Having computed per year the rainy condition cloud attenuation contribution data and the non-rainy condition cloud attenuation contribution data from the measured and logged total attenuation data, then all the processed cloud attenuation contributions data over 2014 - 2017 were integrated and referred to as integrated spectrum analyzer data (ISPAD), shown in Figure 3.

### 2.1. Results of the Radiometric Analysis

The station cloud attenuation distribution for each of the primary cloud models listed in Figure 3 were computed based on their respective representative equation using written Matlab program(s) for each cloud model's representative equation and the extracted radiosonde data. Then Ota cloud attenuation cumulative distribution obtained at the station experimental setup beacon frequency of 12.245 GHz, for each of the primary cloud models and the station 2014 – 2017 ISPAD are compared in the Figure 3, which shows the closest of the existing models to the Ota ISPAD cloud attenuation cumulative distributions is the ITU-R model, next in closeness is the Liebe model, followed by Slobin model. The comparison show a wide gap between the 3.40 dB maximum cloud attenuation of the Ota ISPAD cumulative distribution at 0.01% exceedances to the 0.7913 dB maximum cloud attenuation predicted by its closest ITU-R model. This empirical result prescribes a new model development for the tropical Ota.

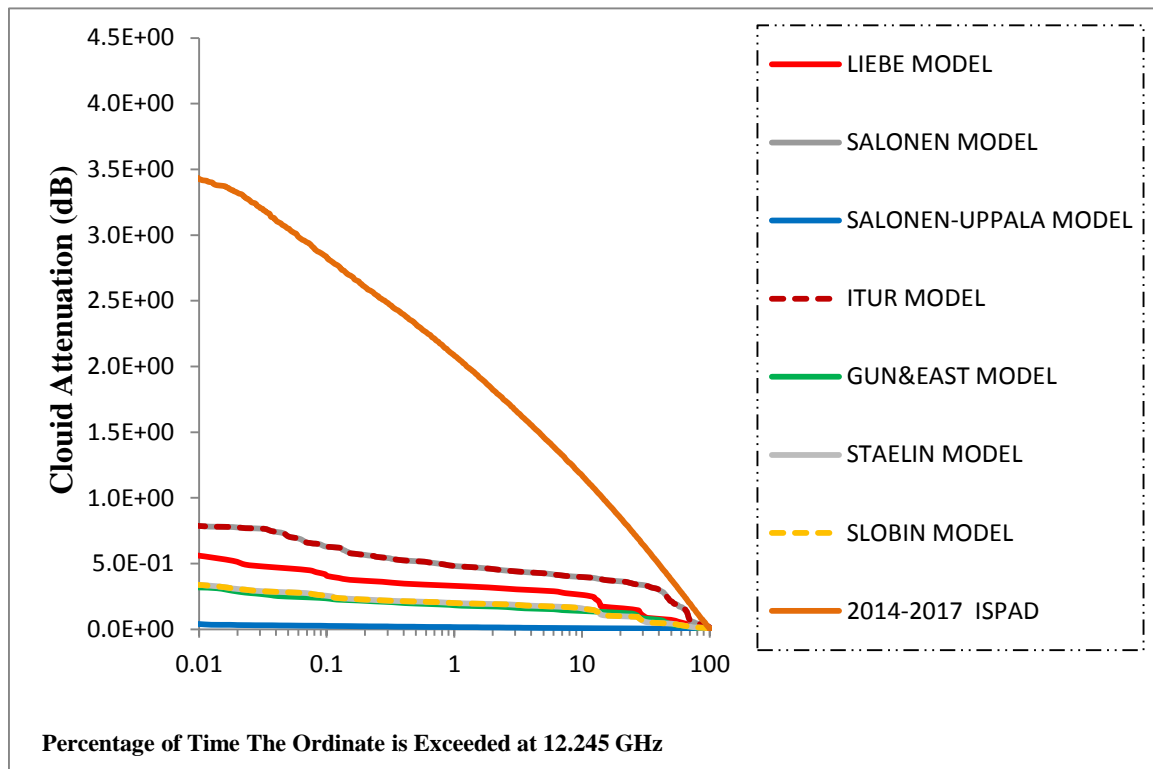


Figure 3: Ota ISPAD and cloud attenuation models cumulative distribution curves at 12.245 GHz

### 3. Development of the New Cloud Attenuation Model

The Ota ISPAD cumulative distribution curve geometry appears to be a resultant constructive interference of some pairs of periodic functions of comparable amplitudes. The scientific consideration for possible variables is in the established cloud physical properties associated with reduction of the amplitude ( $A_0$ ) of propagating electromagnetic waves through the cloud due to its absorption phenomenon; which basically are the cloud liquid water ( $W_L$ ) and cloud attenuation coefficient ( $K_L$ ), both of which varies from one cloud type and layer to another. Thus analyses of these observations propose Equation (1) as a possible general mathematical representation for the cloud attenuation integrated cumulative distribution curve with respect to related trigonometric identity.

$$Ac(W_L(t, h), K_L(\theta, t, f)) = f(x) = a \cos(x) + b \sin(x) = A \cos(x - \alpha) \quad (1)$$

where  $A = (a^2 + b^2)^{1/2}$  and  $\alpha = \tan^{-1}(b/a)$  in the range  $0 < \alpha < \pi/2$ ; the independent variables of the cloud attenuation ( $Ac$ ) are cloud liquid water content ( $W_L$ ) of each cloud layer having specific attenuation coefficient ( $K_L$ ), at corresponding temperature ( $t$ ) and height ( $h$ ), when propagating radio waves through the cloud layer have angle of elevation ( $\theta$ ) and frequency ( $f$ ). The relatively gentle slope of the integrated cumulative distribution curve (Figure 3) indicate that the range of  $x$  should be 0 to  $\pi$  rather than 0 to  $\pi/2$ , hence  $x = 0.5K_L$ . Thus the result of cloud attenuation algorithm development analysis is hereby presented as Equation (2):

$$A_c = A_0 W_L \cos((0.5K_L) + B) \quad 0 \leq K_L \leq \pi \quad (2)$$

Where  $Ac$  is the cloud attenuation (dB) in a cloud layer,  $A_0$  and  $B$  are respectfully the amplitude and phase constant of the propagating signal through the cloud layer, whose liquid water content is  $W_L$  and  $K_L$  is its specific attenuation coefficient as defined by the ITU-R.  $W_L$  and  $K_L$  are computed from

observation station climatic zone radiosonde data. Thus Equation (2) represent general cloud attenuation algorithm that can be used to generate the cloud attenuation model for any station climatic zone, given availability of the integrated spectrum analyzer data (ISPAD) and the radiosonde data for the station.

The specific equation representing the station cloud attenuation model is further developed from the presented cloud attenuation algorithm (Equation 2) through its simulation over possible range of  $A_0$  and B values using a written Matlab program. The simulations at various values of  $A_0$  and B were carried out using the  $W_L(t, h)$  and  $K_L(\theta, t, f)$  data sets generated from the Ota tropical zone radiosonde data (1953 – 2011). Each simulation corresponds to a pair of possible( $A_0, B$ ) values that generate a set of the station cloud attenuation distribution; for which corresponding cumulative distribution curve is obtained. Close simulation cycles parameters are listed in Table 2.

Table 2: Close simulation cycles parameters

Close Simulation	$A_0$	Maximum	Remark
		Attenuation Predicted	
Serial Number	( $\mu\text{m}$ )	(dB)	
10.6	10	3.143	Lie below ISPAD line
10.7	12.5	3.929	Very high above ISPAD line
10.8	12.245	3.849	Very high above ISPAD line
10.9	11.5	3.615	Closest to ISPAD line
11	3.457	3.457	Irregularly Spiral about ISPAD line

The resulting cumulative distribution curve for each simulation cycle is compared with the Ota ISPAD cumulative distribution by placing both of them in the same axes as shown by Figure 4, which shows simulation 10.9 produced the closest match to the station integrated cloud attenuation cumulative distribution at 11.5 and 1.560796 for  $A_0$  and B respectively. Hence Equation (3), the Ota climatic zone cloud attenuation model is hereby presented:

$$A_c = 11.5 W_L \text{COS} ((0.5K_L) + 1.560796) \quad 0 \leq K_L \leq \pi \quad (3)$$

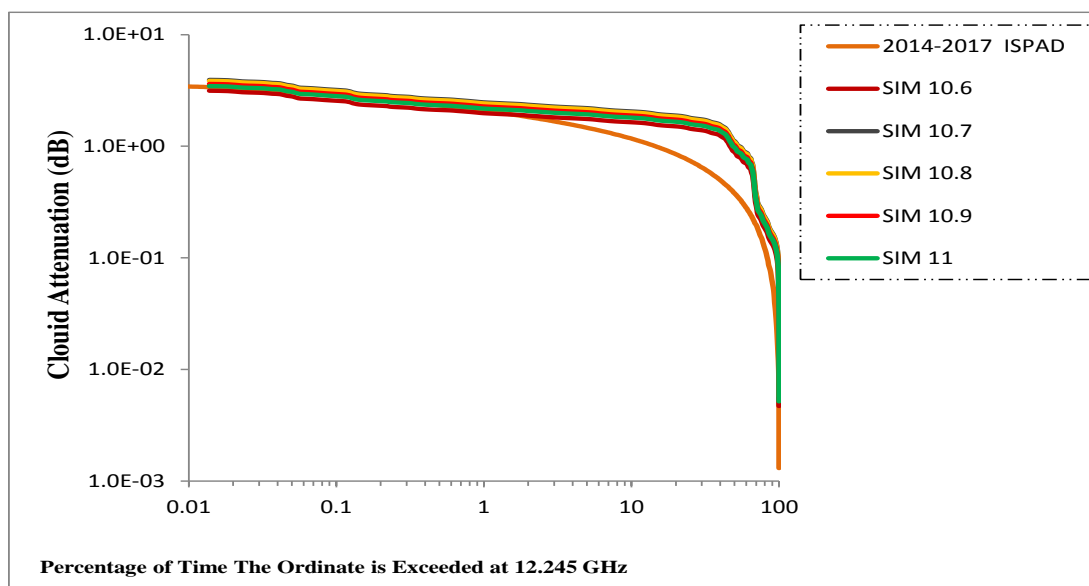


Figure 4: Nearest simulation cycles and ISPAD cumulative distributions

## Conclusion

Having established the need to develop a new cloud attenuation model for the station climatic zone; the station ISPAD cloud attenuation cumulative distribution curve is used to develop the presented general cloud attenuation algorithm derived and presented as Equation (2). Subsequently, the Ota tropical cloud model is deduced from the general algorithm and presented as equation (3) with respect to the station cumulative distributions of the existing cloud models and simulations of the algorithm, considering all required parameters and climatic conditions. This new cloud attenuation model predicted 4.0 dB margin for signals to pass through clouds attenuation effect in the Ota climatic zone, revealing that the predictions for cloud attenuation by the earlier models largely under estimate the margin for the tropical region.

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