Investigation of Low Clouds Attenuation on Earth Space Path for some West-Africa Stations

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Abstract— **The study investigate the contribution of low clouds, to signal fade rate, at Ka band in the satellite communication links on earth-space path(s) to NigComSat 2, from three tropical locations in West Africa. Extracted cloud cover statistical data such as average cloud amount, average base height, and frequency of occurrence, were used to obtain the monthly variations and seasonal variations for Lagos (6.55º, 3.35º), Bouake (7.73º, -5.07º) and Bamako (12.53º, -7.95º). Cloud attenuation statistics were computed for each of the three stations for their respective uplink and downlink. The uplink and downlink attenuation ranges between about 0.2 to 1.6 dB and 0.1 to 0.8 dB respectively for Lagos; for Bouake between 0.005 to 0.035 dB and 0.003 to 0.016 dB respectively; finally, for Bamako between about 0.2 to 2 dB and about 0.1 to 1 dB respectively. The stations downlink attenuation sets of values are generally about twice their corresponding uplink attenuation values.**

Keywords- Clouds; Satellite; Ka band; attenuation; Tropical Locations; West Africa.

I. INTRODUCTION

Rain can be traced to the formation of cloud, at high frequencies such as Ka band (20/30 GHz), experiences signal degradation due to cloud [1]. The tropospheric gases, clouds, rain, and fog absorbs electromagnetic energy, resulting majorly in the signal attenuation and polarization [2-5]. Clouds and fog generally consist of water droplets of less than 0.1mm in diameter, whereas raindrops typically range from 0.1mm to 10mm in diameter [4]. These effects result in a reduction in the quality of analogue transmissions and in increase in the error rate of digital transmissions [5]. In general, the higher the frequency, the more a signal is susceptible to rain fade in the troposphere

For the purpose of cloud impact evaluation, the clouds cover statistical data such as average cloud amount, average base height, and frequency of occurrence, for each of the low clouds – Stratus (St), Cumulus (C) Stratocumulus (Sc), Cumulonimbus (Cb), and Nimbostratus (Ns) were derived from the ground and satellite observations (1971-1996) [6], for the three stations – Lagos, Bouake and Bamako.

Also, daily radiosonde measurements data (1953-2011) were retrieved from Integrated Global Radiosonde Archive, for the three locations – based on Salonen (1990) Model [2]. The 'cloud liquid water' for each of the three stations were calculated, using a written Matlab program, imported into their respective Excel worksheets, previously loaded with the stations respective temperature (T), pressure (P) and calculated geopotential height (CALCGPH) data. Outputs of these were used to compute the 'cloud attenuation' (A), for each of the three stations' earth – space path at the Ka band, through two other written programs – one for computation of their respective 'elevation angle' (θ) and the other is a programming of the ITU – R (2009), [7] functional relations between the 'total columnar content of liquid water' (L), 'specific attenuation coefficient' (K_L), and other parameters listed above.

II. DATA PROCESSING AND ANALYSIS

A. The Cloud Cover

The extracted cloud cover statistical data include: 'average cloud amount', 'average base height' and 'frequency of occurrence' for each of the low clouds, obtained from ground and satellite observations (1971-1996). For each of the stations, Day – Night average values were extracted for each month of the twenty-five years period, and their respective monthly and seasonal variations charts were constructed. Thus: the seasonal variations with the clouds' average base heights are illustrated in constructed charts, shown in Figs: 1, 2, and 3, for Lagos, Bamako and Bouake respectively; the frequency of occurrence charts illustrating the monthly variations of the clouds cover are shown in Fig. 4, for Lagos [LAG], Bouake [BUK] and Bamako [BMK].

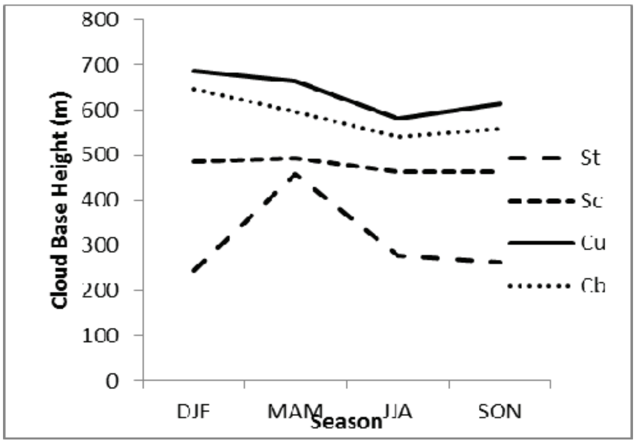

Figure 1. LAGOS Seasonal Average Base Height

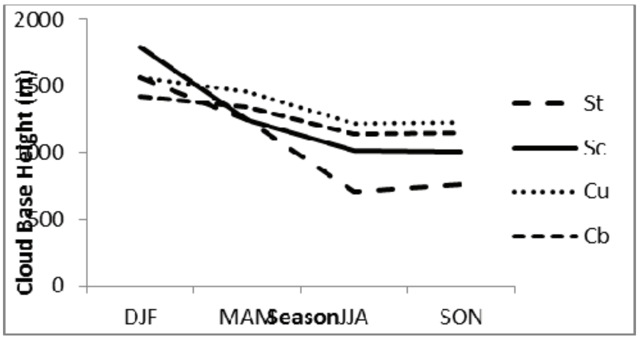

Figure 2. BAMAKO Seasonal Average Base Height

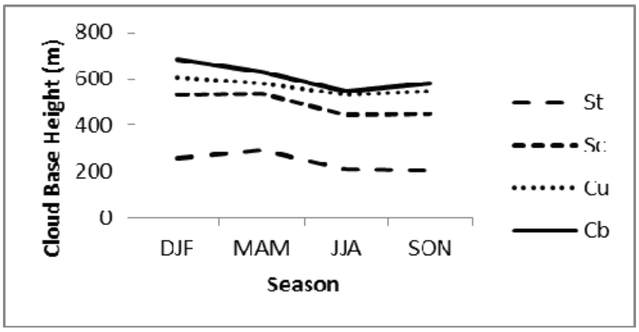

Figure 3. BUAKO Seasonal Average Base Height

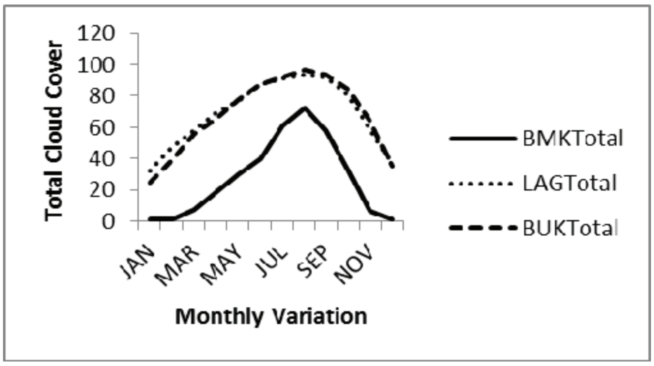

Figure 4. Cloud Cover Frequency Of Occurrence

B. Total Cloud Liquid Water Distribution

The consolidated radiosonde data was filtered, using Microsoft Excel's 'filter application' into cloud level values for required variable as pressure (PRESS) temperature (TEMP) and Calculated Geopotential Heights (CALCGPH). The set of values for the three variables were extracted from the radiosonde observations for range of periods between 1953 and 2011

The data structure include a number of cloud levels per day – which varies between 2 and 82 levels per day, in the period of 1968 – 2011, for Bamako; between 4 and 52 levels per day in the period 1988 to 1997, for Bouake; and between 2 to 45 levels per day in the period 1953 – 2009 for Lagos. The number of values for each of the variables amount to several tens of thousands for the stations, and hence the need to use Matlab R2010b, to compute the cloud liquid water per level for each of the stations.The computed cloud liquid water is summed up per day, to obtain the total cloud liquid water (TCLW). The TCLW column is then filtered to remove blank cells, in each station's excel worksheet. A set of class representative values per station, were obtained from the filtered total cloud liquid water data.

Microsoft Excel's 'data analysis' application was used to obtain the cumulative frequency distribution of each of the stations, following calculation of their probability distribution function. Fig. 5 shows line charts constructed to illustrate total cloud liquid water variations with their corresponding percentage time exceedances, for Lagos [LAG], Bouake [BUK], and Bamako [BMKMaintaining the Integrity of the Specifications.

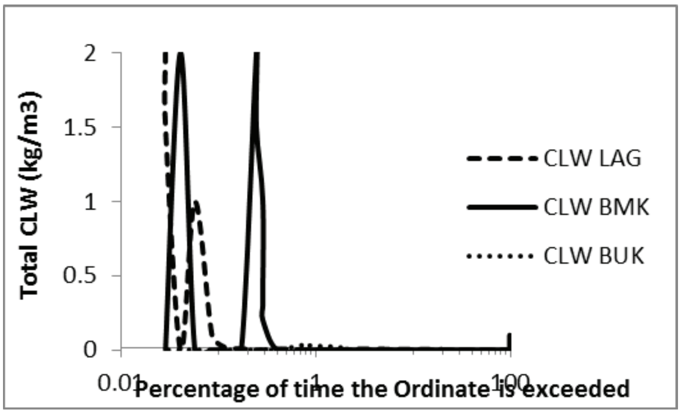

Figure 5: Stations Total Cloud Liquid Water (Tclw) Cumulative Distribution

C. Computation of the Cloud Attenuation

The specific attenuation coefficient (K_L), and the cloud attenuation (A) were computed through programs, for each station, based on the ITU-R (2009) procedure, which includes:

$$A = \{LK_L / Sin\theta\} \text{ dB}, \qquad 90° \geq \theta \geq 5° \qquad (1)$$

Where L is total columnar content of liquid water, θ is elevation angle (EL) and K_L is the specific attenuation coefficient. The outputs of cloud attenuation computations, for each of the three stations are used to construct line charts to illustrate the attenuation distribution for the uplink [A] and down link [A] shown in Figs:6, 7 and 8 below, for Lagos, Bamako and Bouake respectively.

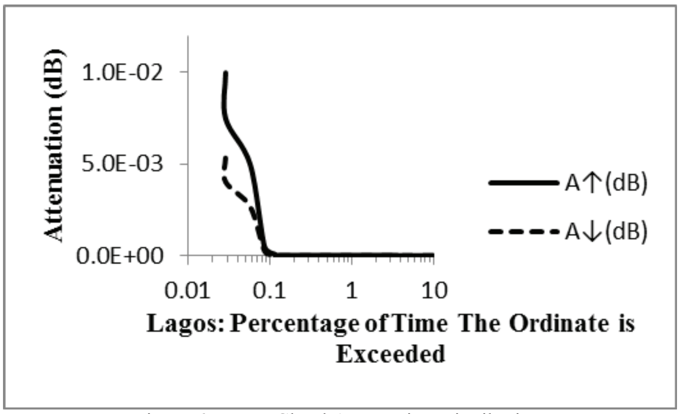

Figure 6: Lagos Cloud Attenuation Distribution

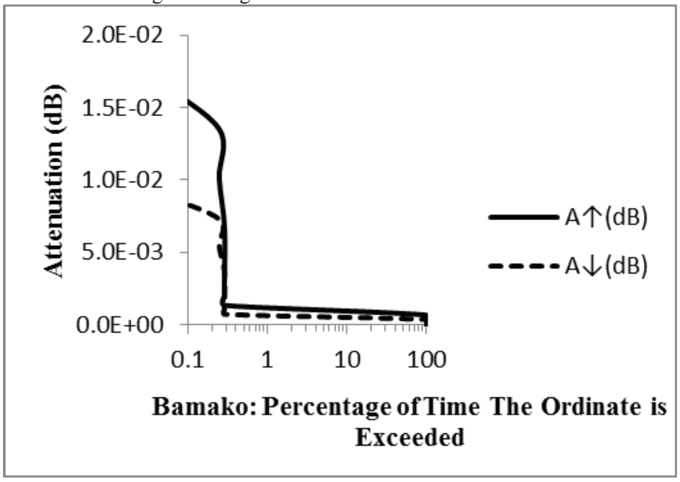

Figure 7: Bamako Cloud Attenuation Distribution

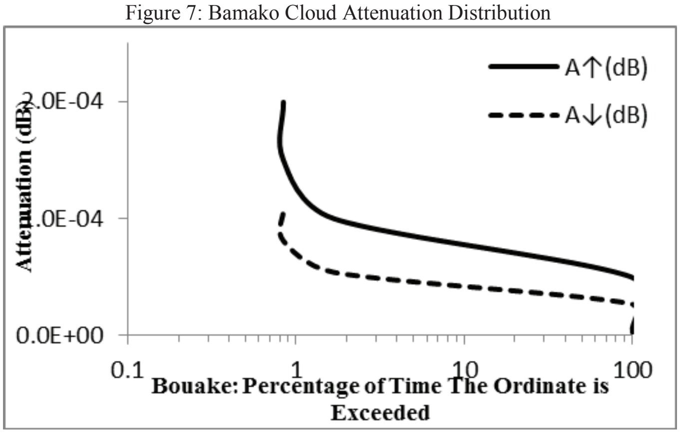

Figure 8: Bouake Cloud Attenuation Distribution

III. RESULTS INTERPRETATION

A. Cloud Cover

Thus for Lagos and Bouake Cu and Cb occurred at highest heights in the first quarter (DJF) and lowest about the 3rd quarter, when the total cloud cover for the two stations were highest -between 90% and 80%. However, for Bamako all the cloud occurred at highest heights in the first quarter and lowest in the 3rd quarter, but the total cloud cover variation was wider than for Lagos and Bouake and the peak is about 70%.

It suggests that some part of the clouds got transformed into rain and other hydrometeors. The cloud cover occurrence is most significant annually from April to October for Lagos and Bouake; while for Bamako the cloud cover occurrence is most significant annually between July and September. The monthly variation of total cloud cover relationship with the frequency of occurrence, indicate that the total cloud cover varies between 32% and about 94% in Lagos; about 25% to 94% in Bouake; and between 1% and 72% in Bamako. This shows high probability of cloud occurrence during an average year for all the three stations, Lagos being the highest of the three.

The seasonal variation of the cloud base height shows a range of 240m to 700m for Lagos, where C has the highest range, while St is the lowest, but the thickest range. For Bouake, the cloud base height range between 200m and 700m, Cb being the highest range, and Sc the lowest range. Bamako cloud base height range is between 700m and 1.8km – the highest range, relative to Lagos and Bouake; here, C has the highest range, except in part of the dry season (i.e. Dec. – Jan.), when the Sc has the highest base height – about 1.8km. During the wet season (April – September), the pressure distribution is low for Bamako area due to high temperature associated with the direct solar impact in the northern hemisphere; while Lagos – a coastal area, experiences high pressure, hence movement of tropical maritime air mass northward from over the Atlantic Ocean.

This increases humidity of the air and therefore the cloud cover, hence the peaks of the three locations occur during this period. In the dry season (October – March), the atmosphere is dry and clouds are virtually absent.

Bamako peculiar cloud distribution could be traced to the combination of the effects of the Atlantic's close range; the passage of River Niger and River Senegal through it; and finally being a desert fringe.

B. Total Cloud Liquid Water

Fig. 5 illustrates total cloud liquid water variation with their corresponding percentage time exceedances, for Lagos, Bouake, and Bamako. Thus for Bouake 0.0001kg/m3 were exceeded all the time; for Bamako 2.0kg/m3 is exceeded about 0.25% of the time, 1.0kg/m3 is exceeded for 0.3% of the time ; for Lagos 2.0kg/m3 is exceeded about 0.03% of the time, 1.0kg/m3 is exceeded for about 0.06% of the time.

C. *Attenuation Distribution*

Thus fig. 6 to 8 shows the cumulative distributions of cloud attenuation at Ka band: for Lagos the cloud attenuation is generated along inclined direction (θ = 44.16°) to the NigComSat2 for 0.01% to 10% exceedances, its uplink attenuation ranges between about 0.2 to 1.6 dB, while the downlink attenuation ranges between about 0.1 to 0.8 dB. Similarly, for Bouake the cloud attenuation is generated along inclined direction (θ = 34.82°), for 0.1% to 100% exceedances. Fig. 8 gives its uplink attenuation is between 0.005 to 0.035 dB, and the downlink attenuation is between 0.003 to 0.016 dB. Also for Bamako, the cloud attenuation is generated along inclined direction (θ = 30.97°) for 0.1% to 100% exceedances. Fig. 7 shows the range of uplink attenuation is about 0.2 to 2 dB and for downlink attenuation it is between about 0.1 to 1 dB. The stations downlink attenuation set of values are generally twice their corresponding uplink values. Thus the satellite link designs for these stations at Ka band need to use margins that should accommodate the stated attenuation ranges.

IV. CONCLUSION

Fig. 1 to 6 shows high probability of cloud occurrence during an average year (well over 50% of the time), for all the three stations. They show a correlation between the total cloud cover and cloud attenuation variations for each of the three stations.

The computed cloud attenuation statistics at Ka band for each of the stations estimated the satellite link design margins thus: for Lagos will be higher than 1.6 dB for uplink and 0.8 dB for downlink; for Bouake, it should be higher than 0.035 dB for uplink and 0.016 dB for downlink; finally for Bamako the margin will be higher than 2 dB for uplink and 1 dB for downlink.

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