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Study of Cloud Impact on Fixed Satellite Communication Link at Ku, Ka and V Bands in Nigeria

T.V. Omotosho, E.B. Babatunde

Department of Physics, Covenant University, Ota, Ogun State, Nigeria

Abstract: The study investigates the effect of clouds on fixed satellite communication link on earth-space path in Nigeria for 0.01 to 10% unavailability of an average year. The input data (from August 2002 to July 2009) used for the study are base on recent meteorological data measured from space by the Atmospheric Infrared Sounder satellites (AIRS). The International Telecommunication Union Radio Propagation Recommendation (ITU-RP, 2009) procedure was used for the computation of cloud attenuation statistics for each of the 37-stations for link to Nigeria Communication Satellite (NigComsat-1), for both uplink and downlink frequencies. At Ku band (12/14 GHz), cloud fade is between 0.2 to 0.55 dB, for Ka band (20/30 GHz), 0.6 to 2.4 dB and for V band (40/50 GHz) 2.0 to 6.0 dB. A Contour map of cloud attenuation at Ku, Ka and V-band for 0.01% unavailability, at 0.1 by 0.1 degree latitude and longitude for downlink and uplink to NigComsat-1 was developed. The maps show consistently that impact of cloud is generally severe in the southern part of Nigeria.

Key words: AIRS satellite, Ku Ka V bands, slant-path Cloud attenuation, fixed satellite communication link.

INTRODUCTION

The current state of the telecommunication market is driven by the increasing demand of the end users for multimedia services, which require high data rates. Within the Fixed Satellite Service, frequency bandwidths wide enough to carry such high data rates are less and less available in conventional C-band to Ku-band but instead at higher frequency bands such as Ka-band or V-band. Cloud impairments are expected to be quite severe in tropical climates like Nigeria due to high occurrence of rainfall. Since rain can be traced to the formulation of clouds and clouds are forms of condensation best described as visible aggregates of minute droplets of water or tiny crystals of ice particles (Rogers and Yau, 1989). The tropical lower atmosphere may be cloudier than temperate region, so standard performances may be difficult to achieve in these regions (Omotosho, 2008; Mc llveen, 1991). Accurate prediction of impairment statistics is thus very important for the design and deployment of satellite systems in tropical regions. Although raindrops have been found to be the most significant hydrometeors affecting radio wave propagation for frequency above 10 GHz, the influence of clouds and fog are very important on earth-space paths links at Ka (20/30GHz) and V (40/50GHz) bands. Many projected Ka-band and V-band services uses small terminals dish (DTHM), about 30cm in diameter and, for these, rain effects may only form a relatively small part of the total propagation link margin (Harris, 2002). But cloud attenuation, that may cause deep fades in these bands, is one of the components that need to be considered for low availability satellite links owing to its higher probability of occurrence (Mandeep and Hassan, 2008). For ease of data analyses in this work, the 37 stations (Fig. 1) in Nigeria have been divided into six distinct regions namely: South–West (SW), South–East (SE), South–South (SS), Middle–Belt (MB), North–West (NW) and North–East (NE)

Cloud Data sources:

The Atmospheric Infrared Sounder (AIRS) Satellite is one of the six instruments on board NASA's Aqua spacecraft launched on May 4 2002. The Spacecraft is positioned in a near-polar orbit around the Earth in synchronization with the Sun, with its path over the ground ascending across the equator at the same local time every day, approximately 1.30 p.m. On the other side of its orbit, Aqua descends across the equator at approximately 1.30 a.m. every day. AIRS uses cutting-edge infrared technology to create 3-dimensional maps of air and surface temperature, water vapour, and cloud properties. With 2378 spectral channels, AIRS has a

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Corresponding Author: T.V. Omotosho, Department of Physics, Covenant University, Ota, Ogun State, Nigeria
Mobile: +23408050401655
E-mail: dayovic@yahoo.com (T.V. Omotosho).

spectral resolution more than 100 times greater than previous IR sounders and provides more accurate information on the vertical profiles of atmospheric temperature and moisture content. AIRS can also measure trace greenhouse gases such as ozone, carbon monoxide, and methane. AIRS and AMSU-A share the Aqua satellite with the Moderate Resolution Imaging Spectro-radiometer (MODIS), Clouds and the Earth Radiant Energy System (CERES) and the Advance Microwave Scanning Radiometer-EOS (AMRS-E). Aqua is part of NASA's "A-train" a series of high-inclination, sun-synchronous satellites in low Earth orbit designed to make long-term global observation of the land surface, biosphere, solid earth, atmosphere and oceans. The AIRS measured profiles of Temperatures, Pressure, Relative humidity, and Geopotentials (from 2002-2009) data have been used as input parameters for the study of cloud attenuations at the 37 stations in Nigeria. Figure 1 shows, the maps of the 37-stations

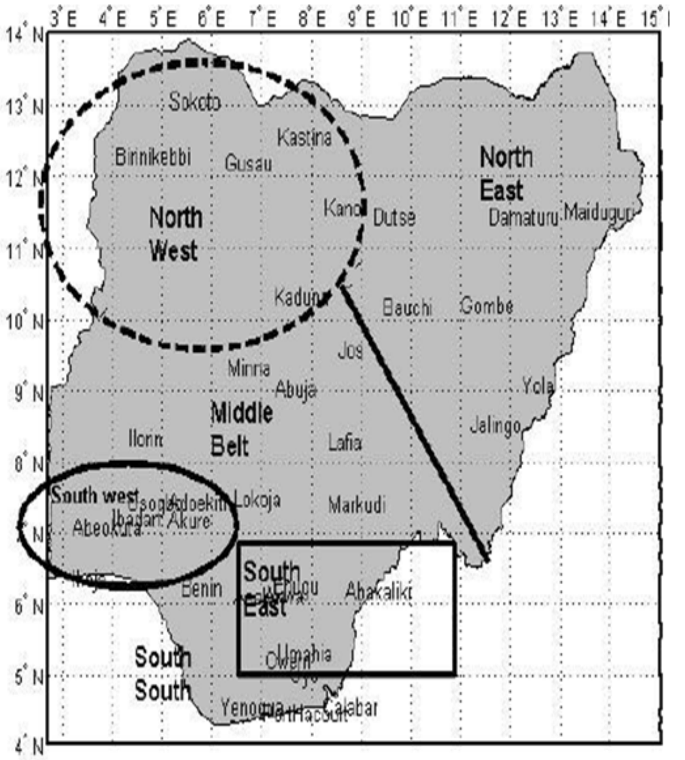

Fig. 1: Map of Nigeria showing the 37 stations used in the study.

Data Processing Total Columnar Content (TCC) of Liquid Water:

The daily measured profiles of temperature T (K), Pressure P (hpa) and relative humidity RH, (%) ascending data of AIRS satellite were averaged for each of the 37 stations. The seven year average values were used in the evaluation of the total columnar content of liquid water (TCC). The calculation of the (TCC) from radiosonde measurements is based on the model proposed by (Salonen *et al.,* 1990). Computer Program was used to evaluate TCC the programs name was, TCLWC, written in Matlab 7.0 to evaluate the Salonen et al model. The function can be called in Microsoft excel taking input arguments such profiles of temperature, pressure, acceleration due to gravity, relative humidity, geopotential height e.t.c. Table 1 shows the evaluated results of TCC (kg/m^2 from 0.01 to 10% unavailability) and surface temperature T(K). The results show that TCC (kg/m^2) decreases toward the northern part of Nigeria while surface temperature T (K) decreases toward the southern part of Nigeria. For example at 0.01% unavailability TCC in the south-south is 2.8 kg/m^2 in the north-west and north-east 1.9kg/m^2.

Calculation of Total columnar content of liquid water in clouds (TCC):

The calculation of the columnar liquid water content of clouds from radiosonde measurements is based on the model proposed by (Salonen *et al.,* 1990). The cloud detection is performed using the "critical humidity" function defined as follows:

$$U_c(P) = 1 - \alpha\sigma(1-\sigma)[1+\beta(\sigma-0.5)] \tag{1}$$

where

$\sigma = p/p0$ is ratio of the atmospheric pressure at the considered level and the pressure at ground

Within the cloud layer the water density *w (g/m* ^{3}*)* of any slice of the upper air sounding is a function of the air temperature, t [ºC], and of the layer height, h [m]:

$$w(t,h) = w_0 \cdot \exp(ct) \cdot \left(\frac{h-h_b}{h_r}\right) \tag{2}$$

where: $w_0 = 0.17$ *(g/m* ^{3}*)*

$c = 0.04({}^0C^{-1})$ = *temperature dependence factor*

$h_r = 1500m$

h_b = *cloud base height (m)*

The liquid and solid water density, w_l and w_i are given by:

$$\begin{aligned} w_l(t,h) &= w(t,h) \cdot p_w(t) \\ w_i(t,h) &= w(t,h) \cdot [1 - p_w(t)] \end{aligned} \tag{3}$$

where P_w *(t)* is the fraction of cloud liquid or solid water given and is given by:

$$p_w(t) = \begin{cases} 1 & 0 < t \\ 1 + t/20 & -20 < t < 0°C \\ 0 & t < -20 \end{cases} \tag{4}$$

The calculation of both cloud base and top heights is performed by linear interpolation. The Total columnar content of liquid water in clouds TCC was calculated for the 37 locations in Nigeria by adding the contributions from all the layers within the clouds that contain water.

Procedure for Evaluation of Attenuation within the Cloud:

The International Telecommunication Union Radio Propagation Recommendation (TTU-R, 2009) procedure was used for the computation of the Cloud attenuation for each of the 37-stations in Nigeria. The specific attenuation within a cloud or fog can be written as:

$$\gamma_c = K_l M \quad \text{dB/km} \tag{5}$$

where:

γ_c: specific attenuation (dB/km) within the cloud

Kl: specific attenuation coefficient ((dB/km)/(g/m3))

M: liquid water density in the cloud or fog (g/m3).

Specific Attenuation Coefficient:

A mathematical model based on Rayleigh scattering, which uses a double-Debye model for the dielectric permittivity e (*f*) of water, can be used to calculate the value of *Kl* for frequencies up to 1 000 GHz:

$$K_l = \frac{0.819f}{\varepsilon''(1+\eta^2)} \quad \text{(dB/km) / (g/m3)} \tag{6}$$

where *f* is the frequency (GHz), and:

$$\eta = \frac{2+\varepsilon'}{\varepsilon''} \tag{7}$$

The complex dielectric permittivity of water is given by:

$$\varepsilon''(f) = \frac{f(\varepsilon_0 - \varepsilon_1)}{f_p[1+(f/f_p)^2]} + \frac{f(\varepsilon_1 - \varepsilon_2)}{f_p[1+(f/f_s)^2]} \tag{8}$$

$$\varepsilon'(f) = \frac{\varepsilon_0 - \varepsilon_1}{[1+(f/f_p)^2]} + \frac{\varepsilon_1 - \varepsilon_2}{[1+(f/f_s)^2]} + \varepsilon_2 \tag{9}$$

where: $\varepsilon_0 = 77.6 + 103.3\ (q - 1)$ (10)

$\varepsilon_1 = 5.48$ (11)

$\varepsilon_2 = 3.51$ (12)

$\theta = 300 / T$ (13)

with T the temperature (K).
The principal and secondary relaxation frequencies are:

$fp = 20.09 - 142\ (q - 1) + 294\ (q - 1)2$ Ghz (14)
$fs = 590 - 1\,500\ (q - 1)$Ghz (15)

Cloud Attenuation:

To obtain the attenuation due to clouds for a given probability value, the statistics of the total columnar content of liquid water L (kg/m2) or, equivalently, mm of precipitable water for a given site must be known yielding:

$$A = \frac{LK_l}{\sin\theta} \quad \text{dB for} \quad 90° \geq \theta \geq 5° \tag{16}$$

where q is the elevation angle and *Kl* is specific attenuation coefficient evaluated using equations (7 to 15). A computer program named *CloudAtt* was written in Matlab 7.0 for computation of equation (1) to (16) which can be linked to Microsoft excel, taking TCC in Table 1 and cloud temperature of 0^0C (273 K) as the input parameter. The elevation and azimuthal angles for links to NigComsat-1 for each of the 37 stations were calculated and used as one of the input parameters for the calculations of earth-space cloud attenuations at 0.01% unavailability in an average year.

Results of Cloud Attenuation for Links to NigComsat-1 at Ku, Ka and V-band for 0.01-10% Unavailability of an Average Year:

As previously stated, elevation and azimuthal angles for links to NigComsat-1 for each of the 37 locations were calculated and used as one of the input parameters for the calculations of cumulative distributions of cloud attenuations from 0.01% to 10% unavailability. Figure 2 to 4 show the cloud attenuation cumulative distribution for links to NigComsat-1 down link frequencies at Ku (11GHz), Ka (20 GHz), and V (40 GHz) bands from 0.01% to 10% unavailability. At these three bands down link frequencies, 99.99% availability is possible in all the 37 stations in Nigeria. Cloud attenuation is generally very low, at the three bands for all the six regions: At Ku downlink frequency it ranges from 0.01 dB (in NW) to 0.42 dB (in SW). For Ka it ranges from 0.05 (in NW) to 1.34 dB (in SW), while at V-band it ranges from 0.18 (in NW) to 4.9 dB (in SW). These results show consistently that cloud attenuation is generally higher in the SW region than in the NW region of Nigeria and that at V-band, cloud attenuation could become a serious concern for earth-space satellite link in the SW region. At 0.01% unavailability these results suggests that in SW region if a satellite link is designed with small margin of 3 dB at V-band, the link will experience a total fade out of signal due to cloud attenuation even in clear sky conditions.

Table 1: Summary of the input Climatic data, Total Columnar Content from 0.01 to 10% for Computataion of Cloud Attenuations in Nigeria Derived from AIRS Satellite data from AUG 2002-JUL 2009

						Total Columnar Content TTC (kg/m2) % Unavailability of an average											
Regions	State capitals	Average Surface Temperature T (K)	Average Surface Pressure P (hpa)	Latitude of each Station	Longitude of each Station	0.01%	0.10%	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%
South West	Abeokuta	301.6	990.3	7.07	3.21	2.4	2.3	2.1	2.0	1.8	1.7	1.6	1.5	1.4	1.2	1.2	1.1
	Adoekiti	300.6	968.5	7.42	5.13	2.5	2.2	2.1	2.0	1.9	1.8	1.8	1.6	1.5	1.3	1.3	1.3
	Akure	300.6	968.5	7.18	5.12	2.5	2.3	2.1	2.0	1.9	1.9	1.8	1.7	1.6	1.4	1.4	1.3
	Ibadan	300.7	977.7	7.21	4.01	2.5	2.3	2.1	2.0	1.9	1.8	1.7	1.6	1.5	1.3	1.3	1.2
	Ikeja	300.2	1003.5	6.35	3.20	2.6	2.4	2.1	1.9	1.8	1.6	1.5	1.4	1.3	1.2	1.2	1.1
	Osogbo	300.7	977.7	7.42	4.31	2.5	2.2	2.1	2.0	1.9	1.8	1.8	1.6	1.5	1.4	1.4	1.3
South East	Abakaliki	301.7	991.9	6.18	8.70	2.2	2.2	2.1	2.0	2.0	1.9	1.8	1.8	1.7	1.6	1.6	1.5
	Akwa	301.4	988.3	6.12	7.04	2.5	2.4	2.3	2.2	2.2	2.1	2.1	2.0	1.9	1.7	1.7	1.6
	Enugu	298.1	988.3	6.24	7.24	2.5	2.4	2.3	2.2	2.2	2.1	2.0	1.9	1.8	1.7	1.7	1.6
	Owerri	300.4	991.6	5.19	7.07	2.7	2.5	2.3	2.2	2.2	2.1	2.1	2.0	1.9	1.7	1.7	1.7
	Umuahia	300.4	991.6	5.30	7.33	2.6	2.5	2.3	2.2	2.2	2.1	2.1	2.0	1.9	1.7	1.7	1.7
South South	Asaba	300.9	993.8	6.10	6.44	2.7	2.5	2.3	2.2	2.2	2.1	2.1	1.9	1.8	1.7	1.7	1.6
	Benin	300.2	997.6	6.22	5.39	2.6	2.4	2.3	2.1	2.1	2.0	1.9	1.8	1.7	1.5	1.5	1.5
	Calabar	299.6	1009.7	4.55	8.25	2.6	2.4	2.2	2.2	2.1	2.1	2.0	2.0	1.9	1.8	1.8	1.7
	Port harcourt	299.7	987.1	4.43	7.02	2.8	2.5	2.4	2.3	2.2	2.1	2.0	1.9	1.8	1.7	1.7	1.6
	Uyo	300.4	991.6	5.00	7.57	2.7	2.5	2.4	2.3	2.2	2.1	2.1	2.0	1.9	1.8	1.8	1.7
	Yenagoa	299.4	989.4	4.55	6.16	2.5	2.4	2.3	2.2	2.1	2.0	1.9	1.8	1.7	1.6	1.6	1.5
Middle Belt	Abuja	303.1	946.2	9.04	7.28	2.2	2.1	2.0	1.9	1.7	1.5	1.4	1.3	1.2	1.0	1.0	0.9
	Ilorin	302.7	972.0	8.32	4.34	2.5	2.2	1.9	1.8	1.6	1.5	1.4	1.3	1.2	1.0	1.0	0.9
	Lafia	303.6	973.8	8.29	8.34	2.1	2.1	2.0	1.9	1.8	1.6	1.5	1.4	1.3	1.1	1.1	1.1
	Lokoja	301.8	982.4	7.47	6.44	2.5	2.2	2.0	2.0	1.9	1.8	1.7	1.6	1.5	1.3	1.3	1.2
	Markurdi	302.7	991.5	7.41	8.35	2.2	2.2	2.1	2.0	1.9	1.8	1.7	1.6	1.5	1.3	1.3	1.2
	Minna	303.9	980.2	9.33	6.33	2.5	2.2	1.8	1.7	1.5	1.3	1.2	1.0	0.9	0.8	0.8	0.7
	Jos	303.1	920.0	9.58	8.57	2.0	1.9	1.7	1.5	1.4	1.2	1.1	1.0	0.9	0.8	0.8	0.7
North West	Birini Kebbi	306.9	978.8	12.28	4.08	2.3	1.7	0.8	0.5	0.5	0.4	0.3	0.2	0.2	0.1	0.1	0.1
	Gusau	306.3	963.1	12.18	6.27	2.5	1.8	1.1	0.7	0.6	0.5	0.4	0.3	0.3	0.2	0.2	0.2
	Kaduna	303.7	941.0	10.32	7.25	1.9	1.9	1.7	1.4	1.2	1.0	0.8	0.7	0.6	0.5	0.5	0.5
	Kano	304.6	949.0	11.56	8.26	2.1	1.6	1.1	0.8	0.6	0.5	0.4	0.4	0.3	0.3	0.3	0.2
	Kastina	305.7	949.2	12.56	7.33	1.9	1.5	0.8	0.6	0.5	0.4	0.3	0.3	0.2	0.2	0.2	0.2
	Sokoto	306.9	974.4	13.05	5.15	2.1	1.5	0.7	0.4	0.4	0.3	0.3	0.2	0.2	0.1	0.1	0.1
North East	Bauchi	304.2	936.3	10.18	9.46	2.1	1.8	1.4	1.2	1.0	0.9	0.8	0.7	0.6	0.4	0.4	0.4
	Damaturu	306.2	958.8	11.44	11.58	2.1	1.6	1.1	0.9	0.7	0.6	0.5	0.4	0.4	0.3	0.3	0.2
	Dutse	305.8	958.2	11.43	9.25	2.1	1.6	1.1	0.8	0.6	0.5	0.5	0.4	0.3	0.3	0.3	0.2
	Gombe	305.6	966.0	10.19	11.02	2.4	1.9	1.3	1.1	0.9	0.8	0.7	0.6	0.5	0.3	0.3	0.3
	Jalingo	303.1	948.4	8.54	11.22	2.1	1.9	1.6	1.4	1.3	1.1	1.0	0.9	0.8	0.7	0.7	0.6
	Maiduguri	306.8	969.6	11.51	13.09	1.9	1.6	1.1	0.9	0.7	0.6	0.5	0.4	0.4	0.3	0.3	0.2
	Yola	306.1	972.9	9.07	12.24	2.0	1.9	1.5	1.2	1.1	1.0	0.8	0.7	0.7	0.5	0.5	0.5
					max	2.8	2.5	2.4	2.3	2.2	2.1	2.1	2.0	1.9	1.8	1.8	1.7
					min	1.9	1.5	0.7	0.4	0.4	0.3	0.3	0.2	0.2	0.1	0.1	0.1

Contour Map of Cloud Attenuation at Ku, Ka and V-band for 0.01% Unavailability:

Figure 5 to 10 show the contour of cloud attenuation at 0.1 by 0.1 degree latitude and longitude for downlink and uplink to NigComsat-1, at Ku (12/14GHz), Ka (20/30 GHz), and V (40/50 GHz) down link and uplink frequencies bands respectively for 0.01% unavailability in an average year. For the down link frequencies; at Ku bands 99.99% availability is possible in all the 37 stations in Nigeria as cloud attenuations are very low; it ranges from 0.2 dB to 0.42 dB. For Ka it ranges from 0.6 to 1.1, dB while at V-band it ranges from 2.0 to 4.0 dB. These results show consistently that cloud fade is generally higher in the southern part of Nigeria (SW, SE and SS) than in the Northern part of Nigeria and that at V-band, cloud attenuation could become a serious concern for earth-space satellite link in the southern region of Nigeria. At 0.01% unavailability these results suggests that in southern region if a satellite link is designed with small margin of 3 dB at V-band, the link could experience a total fade out of signal due to cloud even in clear sky conditions. For the uplink frequencies; at Ku bands 99.99% availability is possible in all the 37 stations in Nigeria as cloud attenuations are very low; it ranges from 0.3 dB to 0.55 dB. For Ka it ranges from 1.2 to 2.4 dB while at V-band it ranges from 3.0 to 6.0 dB. The uplink results show consistently that cloud fade is very high (up to 6 dB) in the southern part of Nigeria (SW, SE and SS) than the Northern part of Nigeria and that at V-band, cloud attenuation will be more severe for uplink on earth-space satellite link, and the southern region may experience more fade of signal due to cloud even in clear sky (or no rain) conditions.

Conclusions:

Cloud impairments had been investigated at Ku, Ka, and V uplink and downlink frequencies bands for 37-stations in Nigeria 0.01 to 10% unavailability. The data used is base on local meteorological data from recent measurement from space by AIRS satellites from 2002 to 2009. At 0.01% unavailability the results suggests that 99.99% availability is possible at Ku bands in all the 37 stations in Nigeria. But at Ka and V-band, the southern part of Nigeria, could experience a signal fade out of 1.1 to 2.4 dB and 4.0 to 6.0 dB respectively due to cloud even in clear sky conditions.

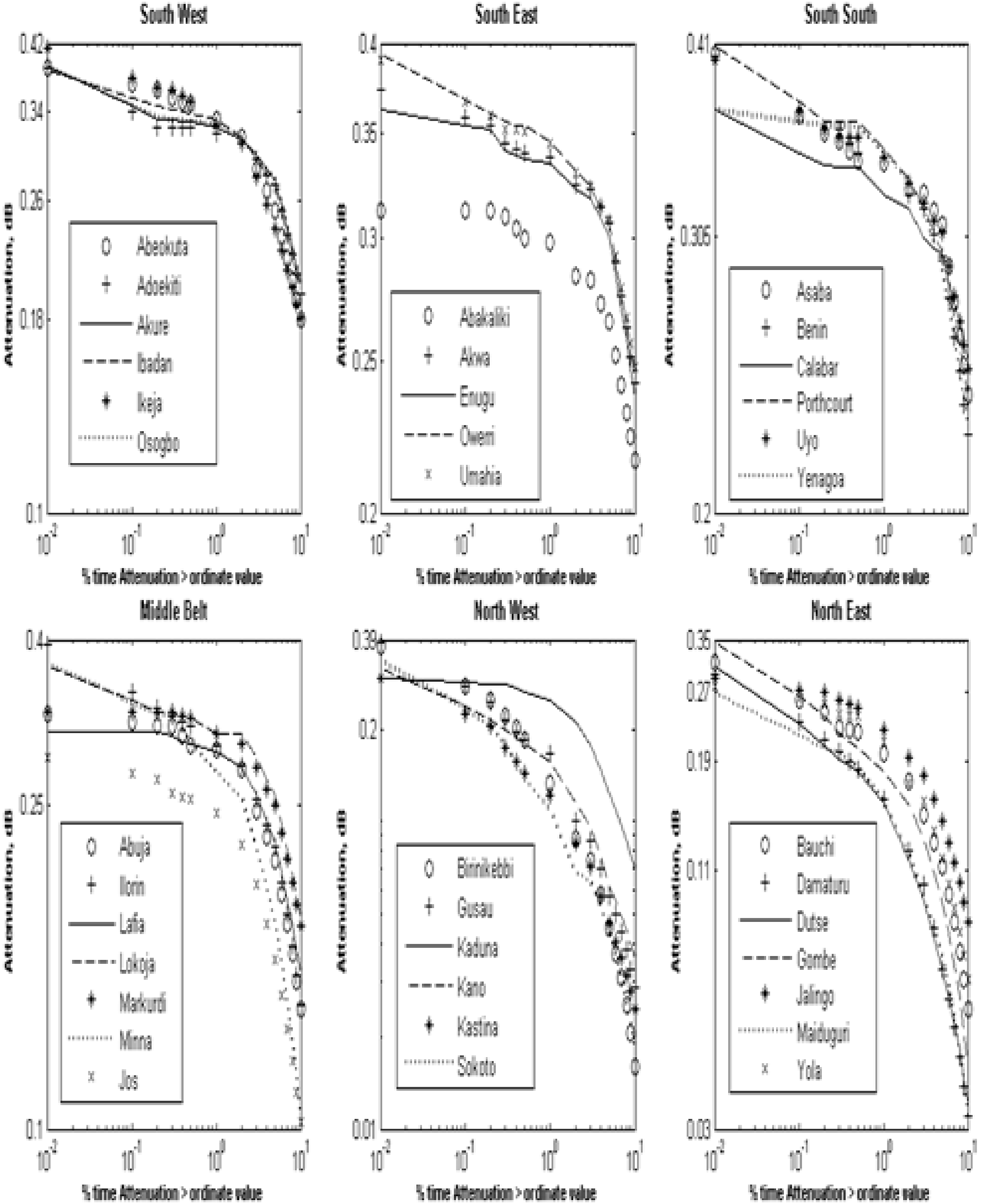

Fig. 2: Cloud attenuation cumulative distribution at Ku (11GHz) downlink from NigComsat-1 for the 37 Locatins

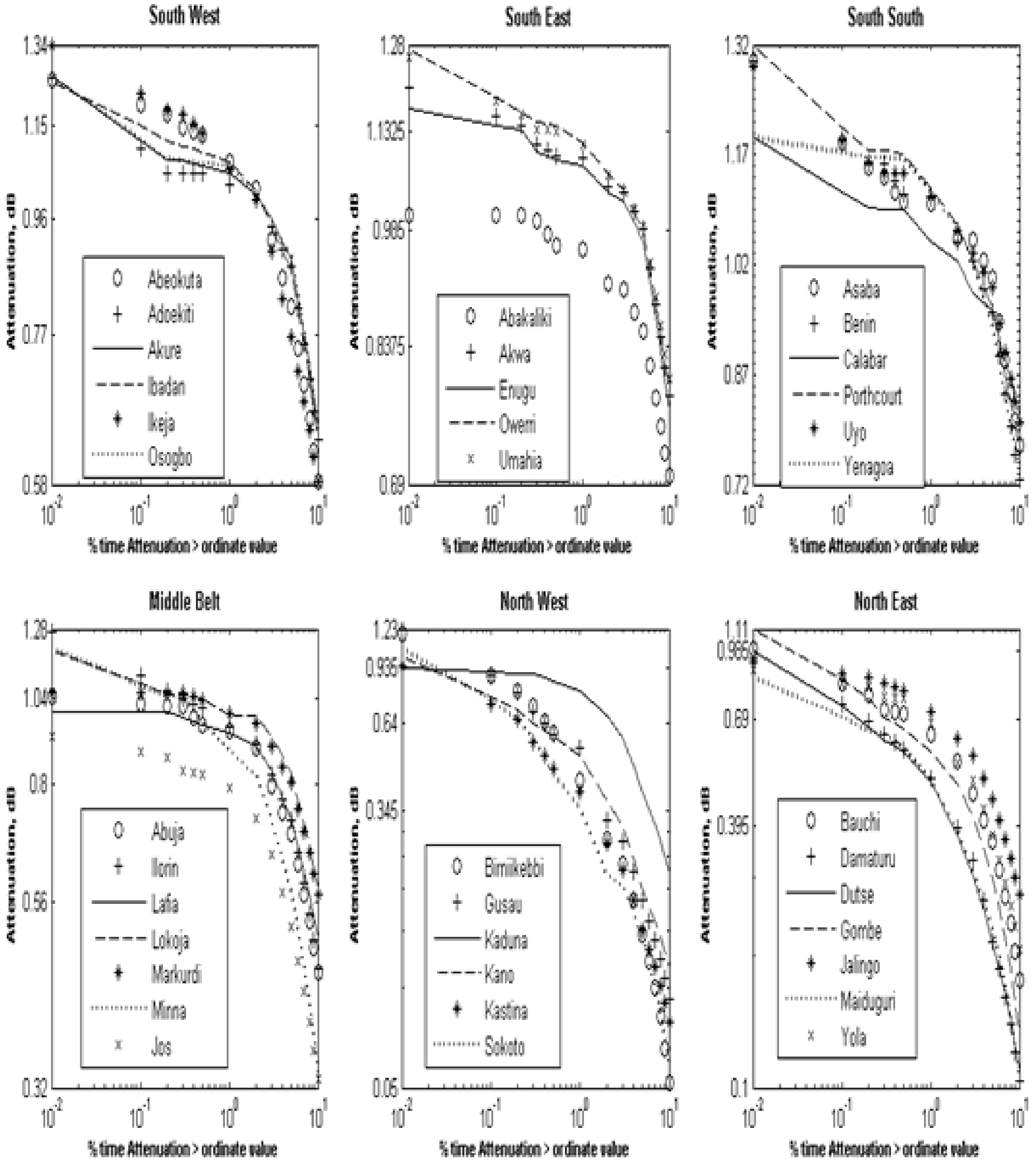

Fig. 3: Cloud attenuation cumulative distribution at Ka (20GHz) downlink from NigComsat-1 for the 37 Locatins

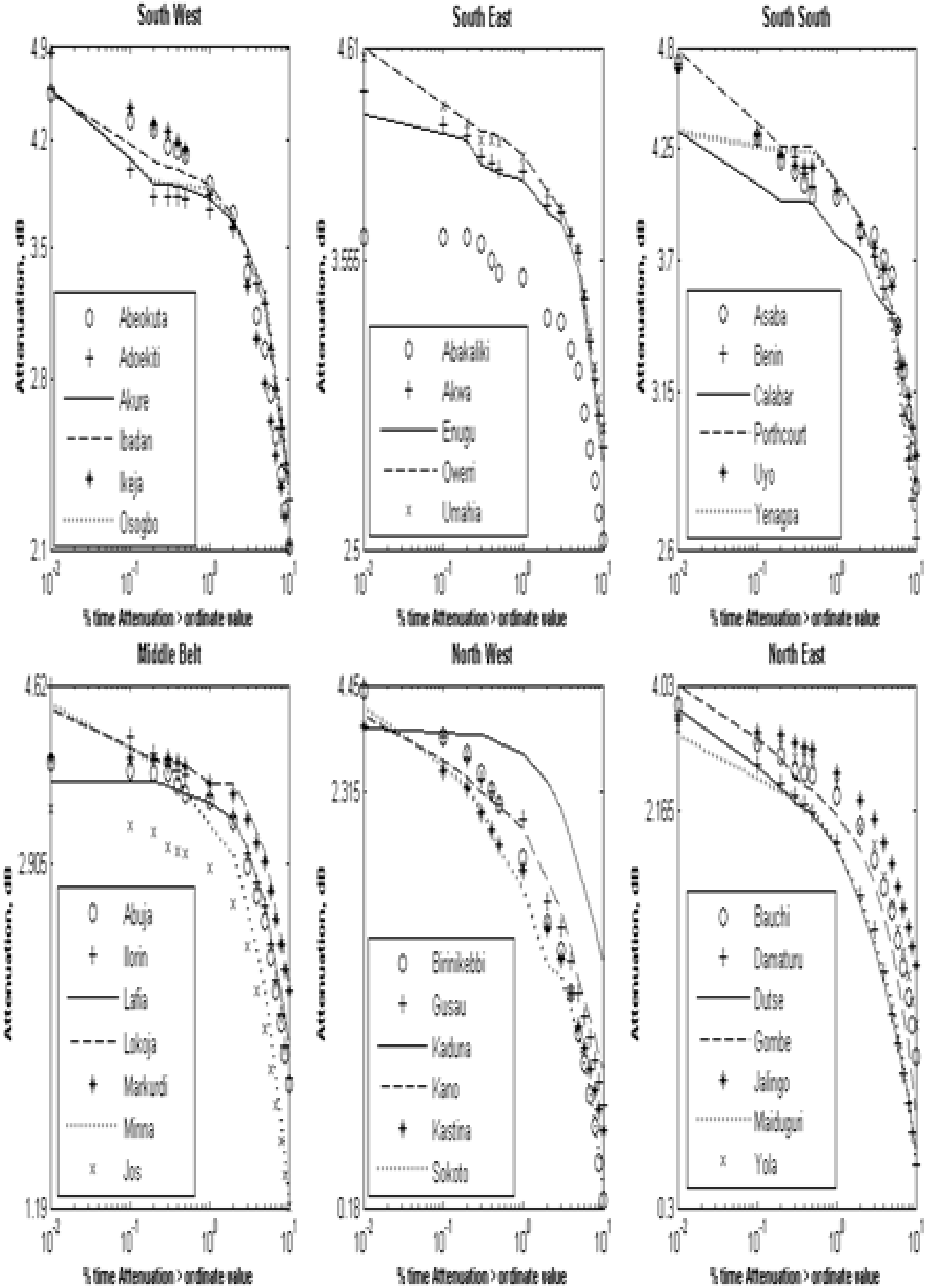

Fig. 4: Cloud attenuation cumulative distribution at V-band (30GHz) downlink from NigComsat-1 for the 37 Locatins

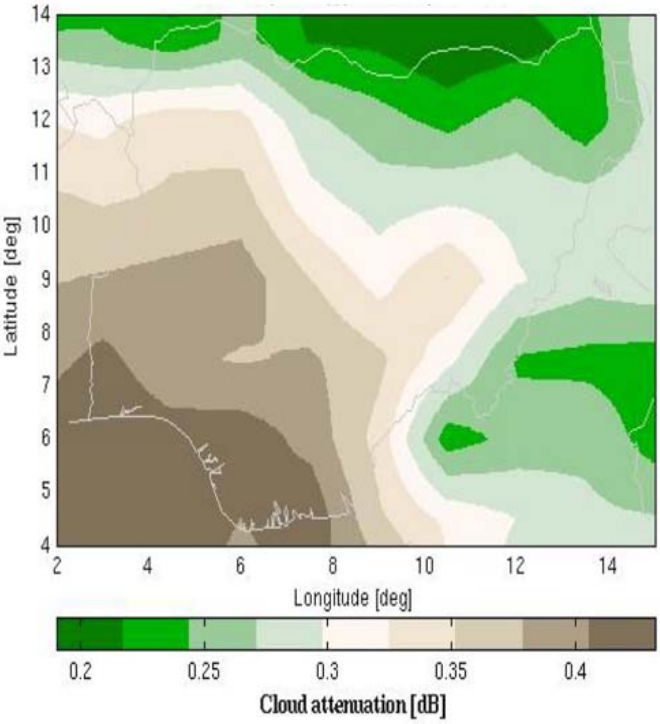

Fig. 5: Contour Map of Cloud attenuation for Ku downlink (12GHz) from NigComsat-1 at 0.01% unavailability

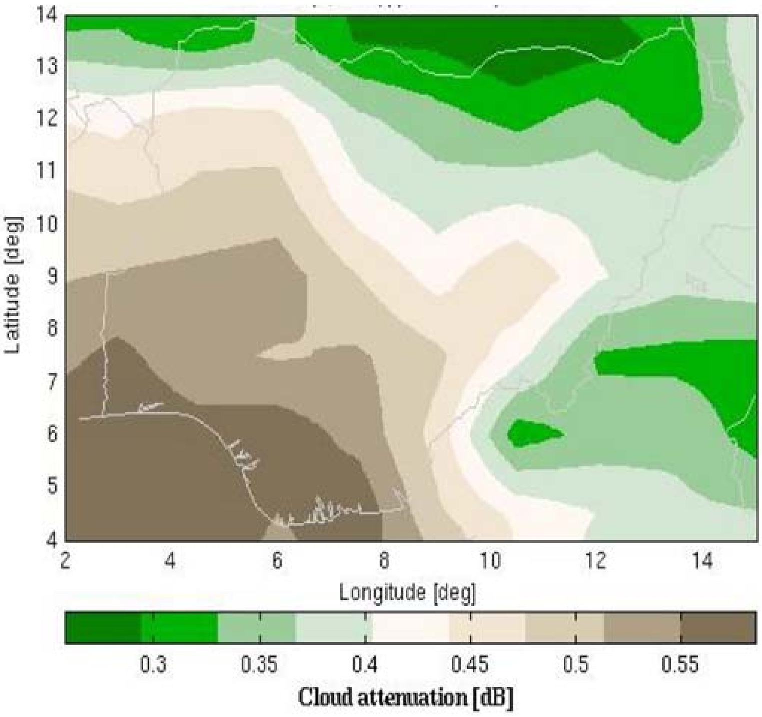

Fig. 6: Contour Map of Cloud attenuation for Ku uplink (14GHz) to NigComsat-1 at 0.01% unavailability

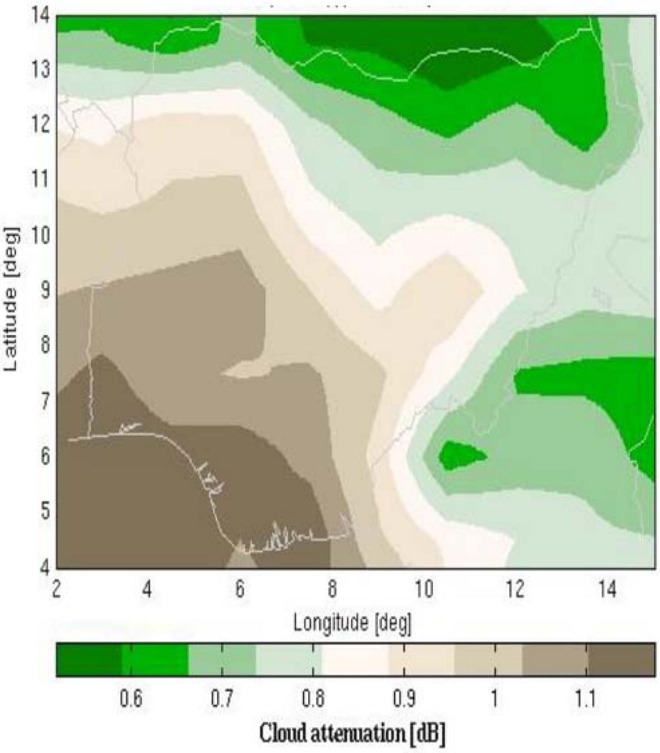

Fig. 7: Contour Map of Cloud attenuation for Ka downlink (20GHz) from NigComsat-1 at 0.01% unavailability

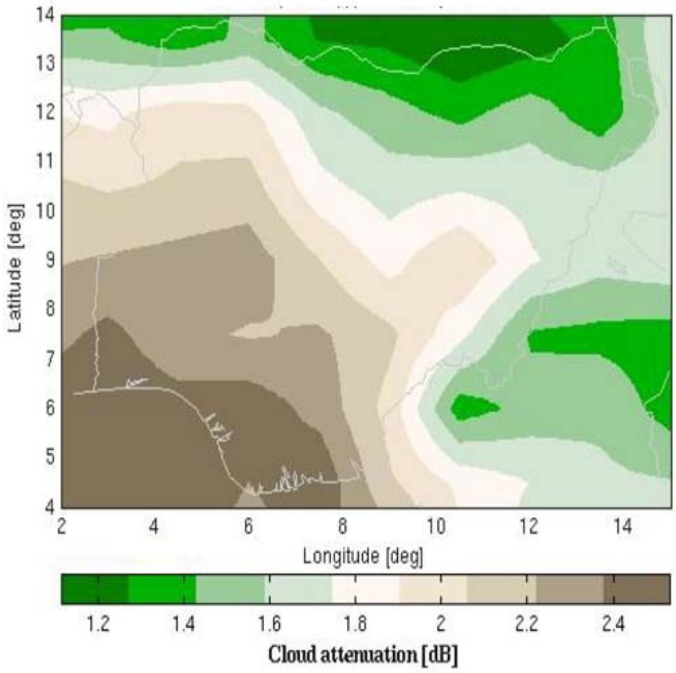

Fig. 8: Contour Map of Cloud attenuation for Ka uplink (30GHz) to NigComsat-1 at 0.01% unavailability

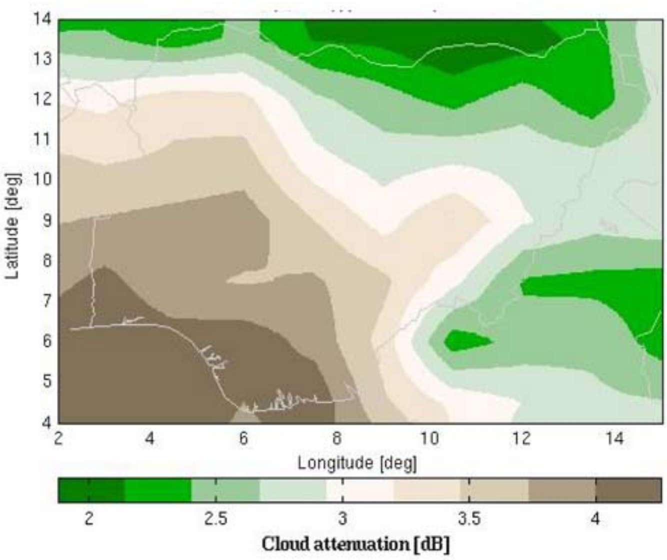

Fig. 9: Contour Map of Cloud attenuation for V downlink (40GHz) from NigComsat-1 at 0.01% unavailability

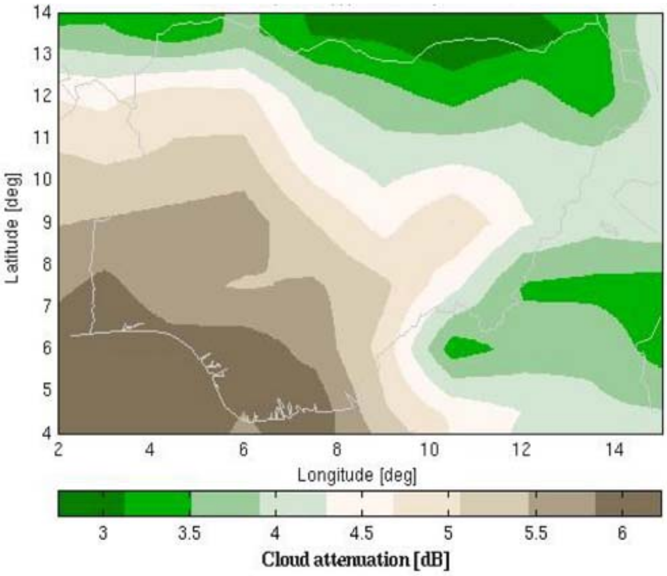

Fig. 10: Contour Map of Cloud attenuation for V uplink (50GHz) to NigComsat-1 at 0.01% unavailability

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