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

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ABSTRACT

Atmospheric absorption accounts for a significant portion of the signal path loss on the Earth-Space link. The total atmospheric absorption due to Oxygen and water vapour on the path at Ku (12/14 GHz), Ka (20/30 GHz), and V (40/50 GHz) bands was evaluated for communication with Nigeria communication satellite (Nigcomsat1) on both uplink and down link at 0.01 % unavailability of an average year. Among the basic input climatic data used are monthly and yearly mean meteorological parameters of surface and vertical profiles of pressure, temperature, and relative humidity obtained from recent measurement from space by the Atmospheric Infrared Sounder (AIRS) instrument on NASA's Aqua spacecraft for the period 2002 to 2009. International Telecommunication Union Radio Propagation Recommendation (ITU-RP 676, 2009) procedure was used for the computation of gaseous attenuation for each of the 37-stations in Nigeria. Attenuation values were obtained for both uplink and downlink frequencies, at Ku, Ka and V bands, total atmospheric absorption was determined to be between (0.11 to 0.24) dB, (0.7 to 1.1) dB and (0.82 to 3.1) dB for Ku, Ka, and V bands respectively. Contour maps showing consistent signal absorption due to Oxygen generally higher in the Southwestern region and water vapour attenuation higher in the South-southern part of Nigeria are presented.

Keywords: *Total atmospheric gaseous absorption; fixed satellite communication; Satellite bands; Satellite Link Analysis.*

1. RELATED WORKS

The principal atmospheric gases, which absorb electromagnetic energy in the microwave frequency range are Oxygen and Water vapor. Atmospheric gases absorb energy from electromagnetic waves if the molecular structure of the gas is such that the individual molecules possess electric or magnetic dipole moments [3]. It is a known fact of quantum theory that at specific wavelengths energy from the wave is transferred to the molecule, causing it to rise to a higher energy level. If the gas is in thermodynamic equilibrium, it will reradiate this energy isotropically as a random process, thus falling back to its prior energy state. Because the incident wave has a preferred direction and the emitted energy is isotropic, the net result is a loss of energy from the wave. The only atmospheric gases with strong absorption lines at millimeter wavelengths are water vapor and Oxygen. The magnetic dipole moment of Oxygen is approximately two orders of magnitude weaker than the electric dipole moment of water vapor. The net absorption due to oxygen is still very high, simply because it is so abundant. The fact that the distribution of Oxygen throughout the atmosphere is very stable makes it very easy to model [4].

The amount of water vapor in the lower atmosphere is highly variable and has surface densities ranging from a fraction of a gram per cubic meter for very arid climates to more than 30 g/m3 for hot and humid regions. Absorption is assumed to be linearly proportional to the water vapor density, except in cases of very high concentrations. Absorption for other water vapor densities may be easily calculated using appropriate models. It is assumed that for clear sky conditions the slant path absorption is proportional to the distance traversed through the absorbing atmosphere [5]. Attenuation by atmospheric gases can be described using either an accurate physical model, such as Liebe's (model) or approximate (probabilistic) models such as the ITU-R P report 676 [6] or Salonen's model [7, 8]. Liebe's models [9, 10, 11, 12] give accurate estimates of air refractivity for frequencies from 1GHz to 1THz, albeit with the downside of computational complexity and a need for vertical profiles of meteorological parameters, whose accuracy has to be carefully ascertained. Hence the use of Liebe's models mainly for reference purposes.

Attenuation by atmospheric gases at millimetric frequencies occurs because of absorption by Oxygen molecules and water vapour in the atmosphere. Gaseous absorption arising from other gases present in the atmosphere is relatively small. Absorption due to Oxygen is nearly constant, while that due to water vapor has a slow rate of change in response to variations in the water vapor content in the atmosphere. As such, increase in gaseous absorption is in correlation with increase in relative humidity as well as temperature. Specific attenuation at frequencies up to 1 THz due to dry air and water vapour can be evaluated most accurately at all values of pressure, temperature and humidity by means of a summation of the individual resonance lines from oxygen and water vapour, together with additional factors for the non-resonant Debye spectrum of oxygen below 10 GHz, pressure-induced nitrogen attenuation above 100 GHz and a wet continuum to account for the excess water vapour absorption found experimentally and presented in [6].

2. INPUT DATA SOURCES FOR GASEOUS ATTENUATION

Absorption is a function of temperature, pressure and humidity. Therefore, it is necessary that these meteorological parameters be determined along the propagation path in order to calculate the gaseous attenuation for any geographical location. Daily surface temperature, pressure, and vertical profiles of temperature, pressure and humidity profiles from the Atmospheric Infrared Sounder (AIRS) instrument on NASA's Aqua spacecraft satellite were used to estimate integrated water vapour content (IWVC). Figure 1 shows the results of the input parameters necessary for the computation of gaseous attenuation derived from AIRS satellite. The gaseous attenuation is calculated along earth-space paths for 37 stations at 12, 14, 20, 30, 40 and 50 GHz frequencies for Ku, Ka and V band downlink and uplink respectively. For a normal clear atmosphere (free of inversions) the absorption of electromagnetic waves is directly proportional to the length of the propagation path through the absorbing medium [4].

Regions	State capitals	Average Surface Temperature T (K)	Average Surface Pressure P (hpa)	Average Water vapour Density $WVD\ (g/m^3)$	Intergrated Water Vapour Content for 1% Unavailability $IWVC\ (kg/m^2)$
	Abeokuta	301.6	990.3	15.93	38.99
South West	Adoekiti	300.6	968.5	13.62	39.27
	Akure	300.6	968.5	13.62	39.27
	Ibadan	300.7	977.7	14.61	39.08
	Ikeja	300.2	1003.5	16.92	38.87
	Osogbo	300.7	977.7	14.61	39.08
	Abakaliki	301.7	991.9	16.38	41.34
South East	Akwa	301.4	988.3	15.97	41.23
	Enugu	298.1	988.3	15.97	41.23
	Owerri	300.4	991.6	16.44	39.66
	Umuahia	300.4	991.6	16.44	39.66
	Asaba	300.9	993.8	16.50	40.96
South South	Benin	300.2	997.6	16.40	39.73
	Calabar	299.6	1009.7	18.96	43.20
	Port harcourt	299.7	987.1	16.21	42.31
	Uyo	300.4	991.6	16.43	41.37
	Yenagoa	299.4	989.4	16.53	41.20
	Abuja	303.1	946.2	11.38	37.68
Middle Belt	Ilorin	302.7	972.0	14.30	38.78
	Lafia	303.6	973.8	14.48	39.18
	Lokoja	301.8	982.4	15.46	40.16
	Markurdi	302.7	991.5	15.69	39.07
	Minna	303.9	980.2	14.29	37.86
	Jos	303.1	920.0	11.63	37.87
	Birini Kebbi	306.9	978.8	10.42	33.92
North West	Gusau	306.3	963.1	8.74	33.86
	Kaduna	303.7	941.0	11.37	35.53
	Kano	304.6	949.0	8.46	33.82
	Kastina	305.7	949.2	7.36	34.07
	Sokoto	306.9	974.4	9.48	33.34
	Bauchi	304.2	936.3	8.89	36.90
North East	Damaturu	306.2	958.8	8.32	34.87
	Dutse	305.8	958.2	7.73	34.37
	Gombe	305.6	966.0	12.27	37.82
	Jalingo	303.1	948.4	13.79	39.87
	Maiduguri	306.8	969.6	11.72	34.72
	Yola	306.1	972.9	13.68	37.34

Figure 1. Summary of input climatic data for computation of gaseous attenuations derived from AIRS satellite data from September 2002 to July 2009

3. GASEOUS ATTENUATION COMPUTATION PROCEDURE

ITU-RP 676 (2009) procedure valid for frequencies between 1GHz and 350GHz [6] was used for the computation of the gas attenuation on earth-space path for each of the 37 stations in Nigeria. A Matlab script named *Space676S.m* was written in Matlab 7.0 to implement the equations in the procedure. The script can be linked to Microsoft excel and called as a function taking input parameters such as frequency, pressure, water-vapour density, and temperature.

4. RESULTS AND DISCUSSION

Figure 2 shows the map of Nigeria with the positions of the 37 observation stations and their respective geographical sub-groups. Contour maps of Oxygen and water vapour attenuation for downlink and uplink to *NigComsat-1* at Ku, Ka, and V frequency bands respectively for 0.01% unavailability (i.e. 53 minute outage) in an average year are depicted on figures 3 through 10. For the downlink frequencies: at Ku band 99.99% availability is possible in all the 37 stations in Nigeria due to very low gas attenuation with values ranging from 0.11 dB to 0.18 dB; for Ka band it ranges from 0.7 to 1.1 dB, while at V band it ranges from 0.82 to 1.31 dB.

The results show consistently that gas fade is generally higher in the SW, SE and SS part of Nigeria than in the Northern part of Nigeria and that at V band gas attenuation could become a serious concern for earth-space satellite link in the southern region of Nigeria. At 0.01% unavailability these results suggest that in the southern region if a satellite link is designed with a small margin of 1dB for gas attenuation at V band, the link could experience 100% fadeout of signal even under clear sky conditions. For the uplink frequencies; at Ku band it is seen that 99.99% availability is possible in all the 37 stations in Nigeria as gas attenuation is very low; it ranges from 0.15 to 0.24 dB. Attenuation for Ka band ranges from 0.65 to 0.98 dB, while at V band it ranges from 2.0 to 3.1 dB. The uplink results show consistently that atmospheric gas attenuation is very high in the southern part of Nigeria (SW, SE and SS) relative to the Northern part of Nigeria and that at V band gas attenuation will be more severe for uplink on earth-space satellite link and the southern region may experience more fade of signal due to atmospheric gas attenuation even in clear sky conditions.

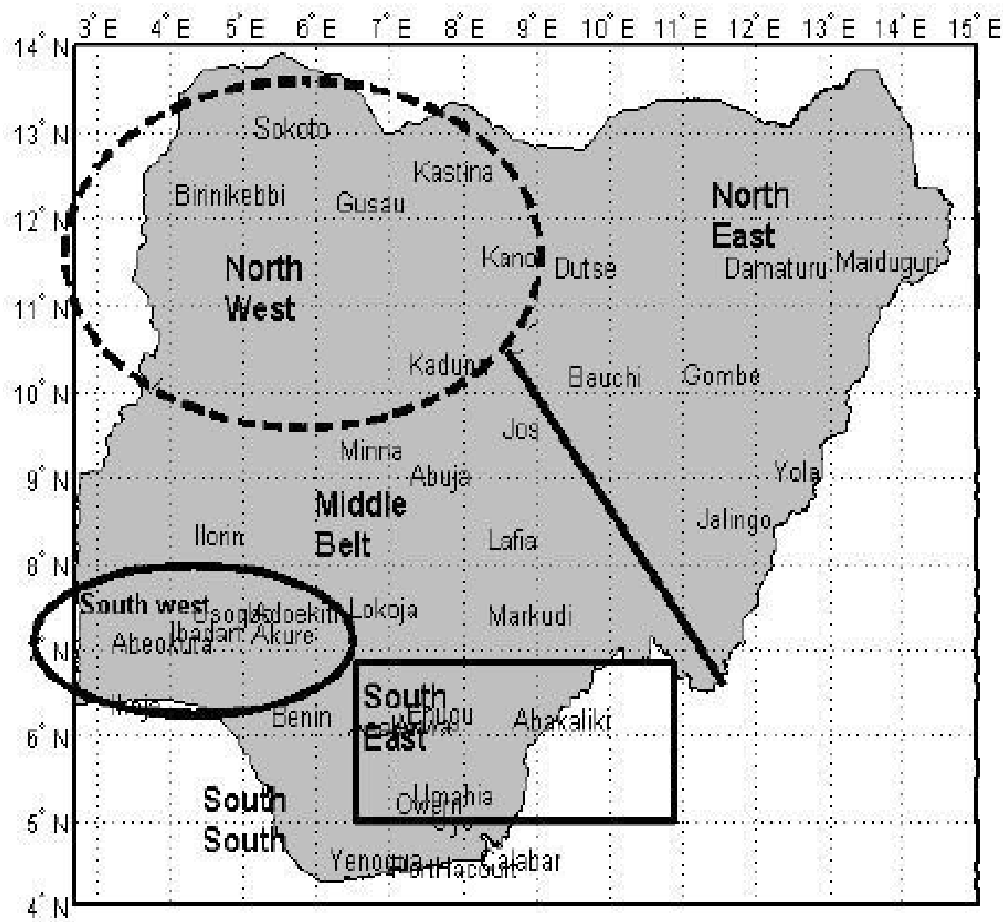

Figure 2. Map of Nigeria showing the locations of the 37 stations used in the study.

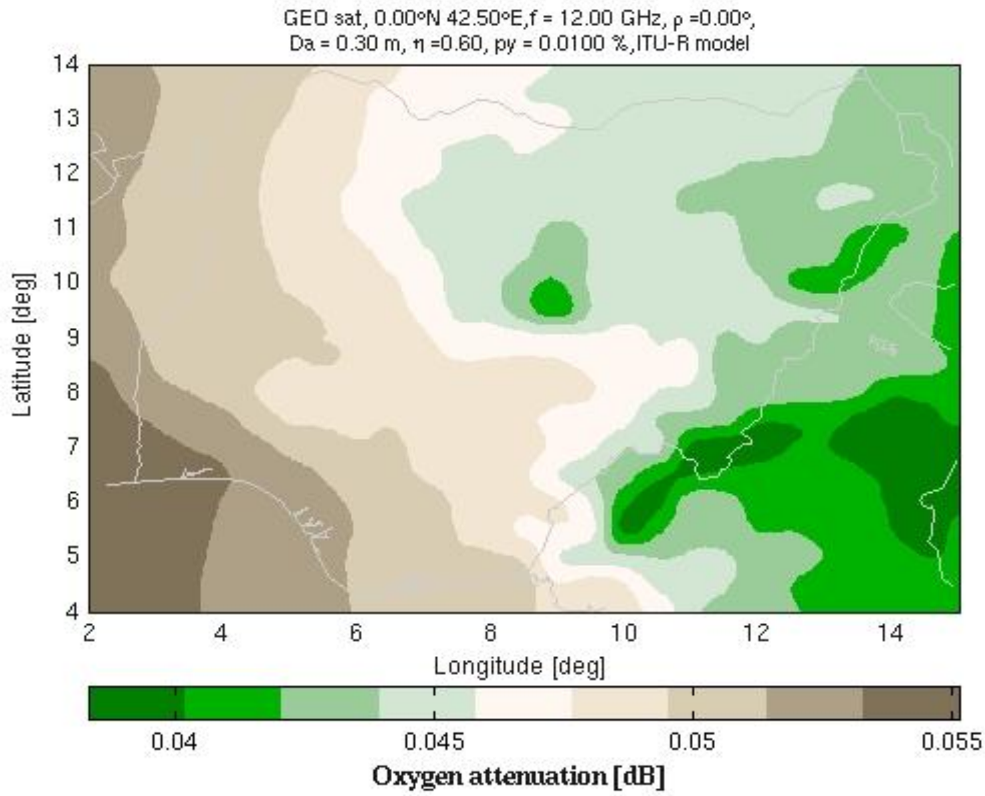

Figure 3. Contour map of oxygen attenuation for Ku downlink (12 GHz) from NigComsat-1 at 0.01% unavailability

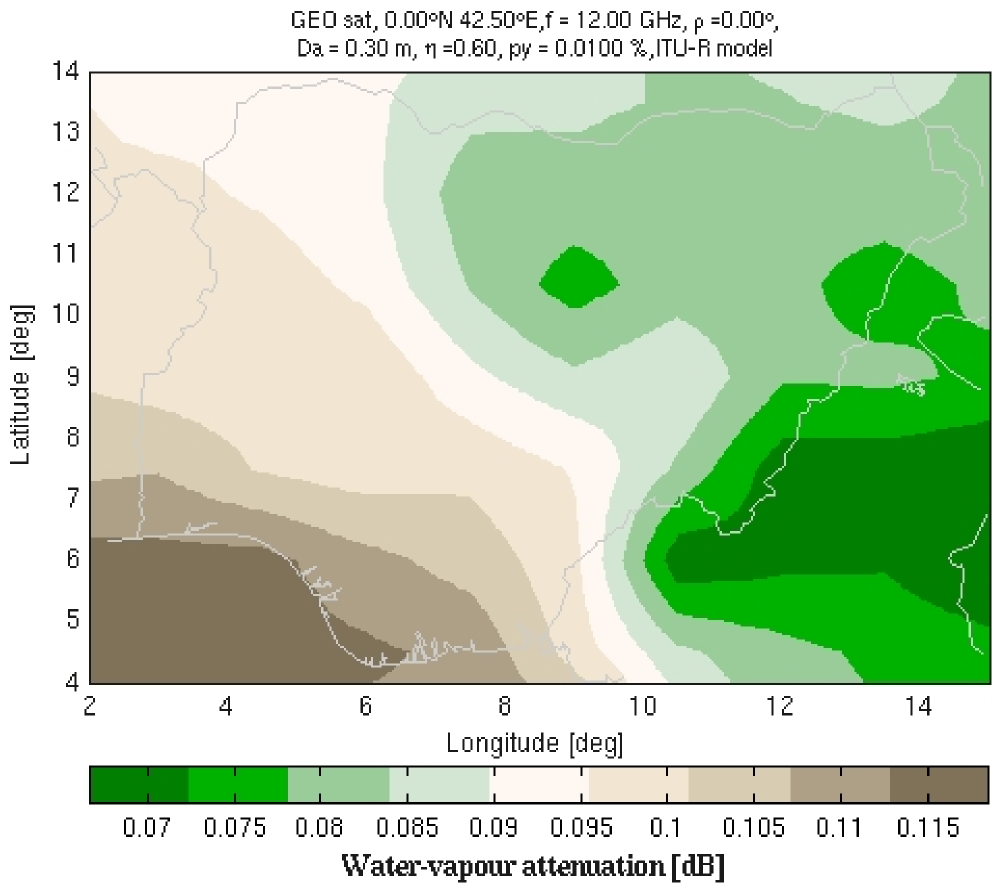

Figure 4. Contour map of water-vapour attenuation for Ku downlink (12 GHz) from NigComsat-1 at 0.01% unavailability

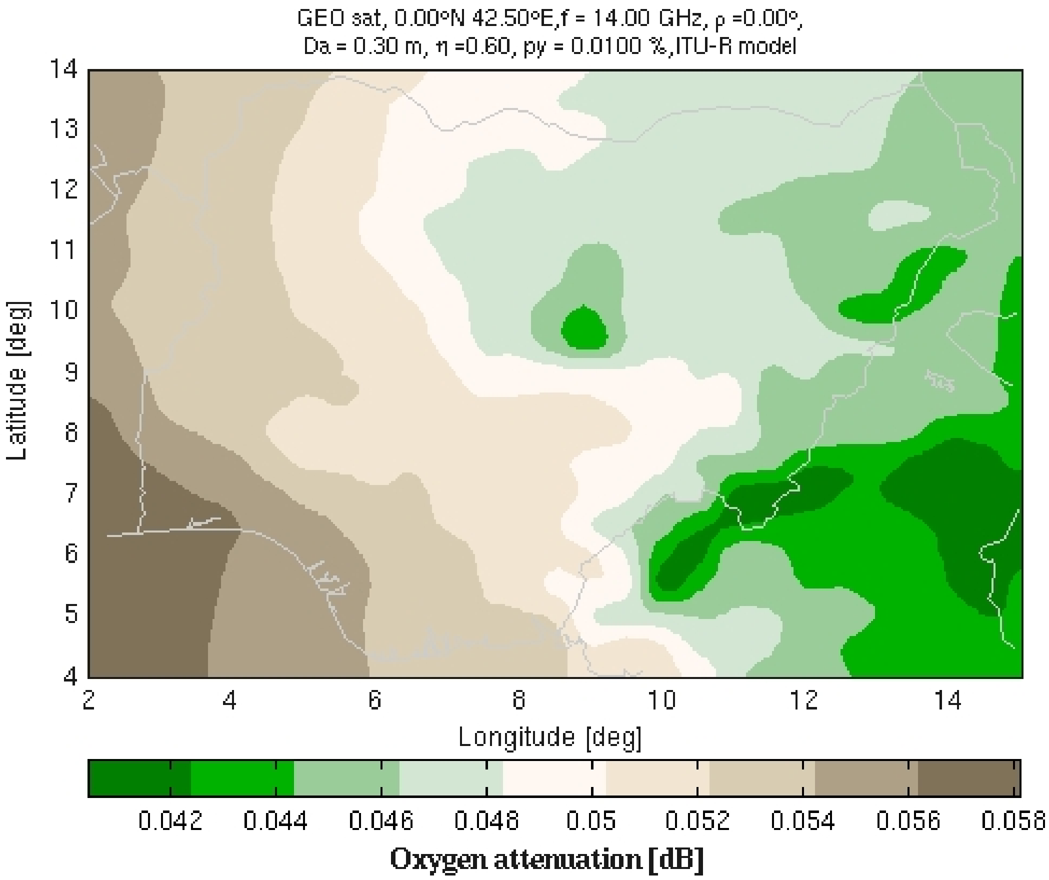

Figure 5. Contour map of water-vapour attenuation for Ku uplink (14 GHz) to NigComsat-1 at 0.01% unavailability.

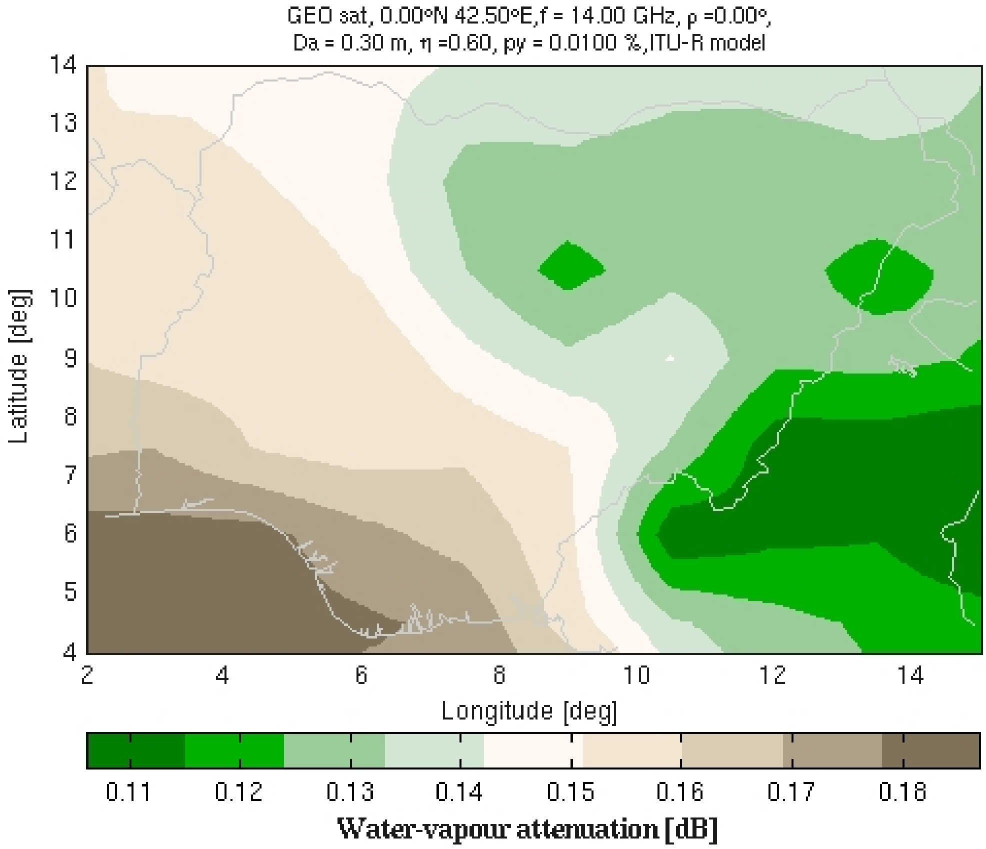

Figure 6. Contour map of water-vapour attenuation for Ku uplink (14 GHz) to NigComsat-1 at 0.01% unavailability.

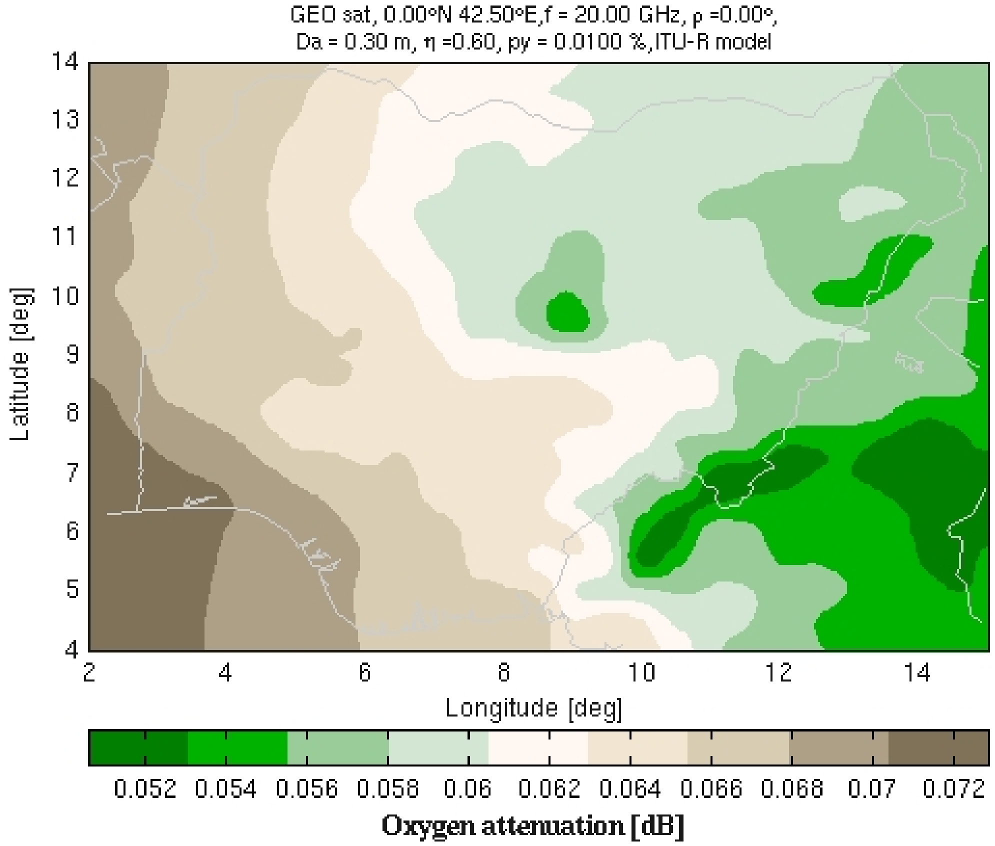

Figure 7: Contour map of oxygen attenuation for Ka downlink (20 GHz) from NigComsat-1 at 0.01% unavailability

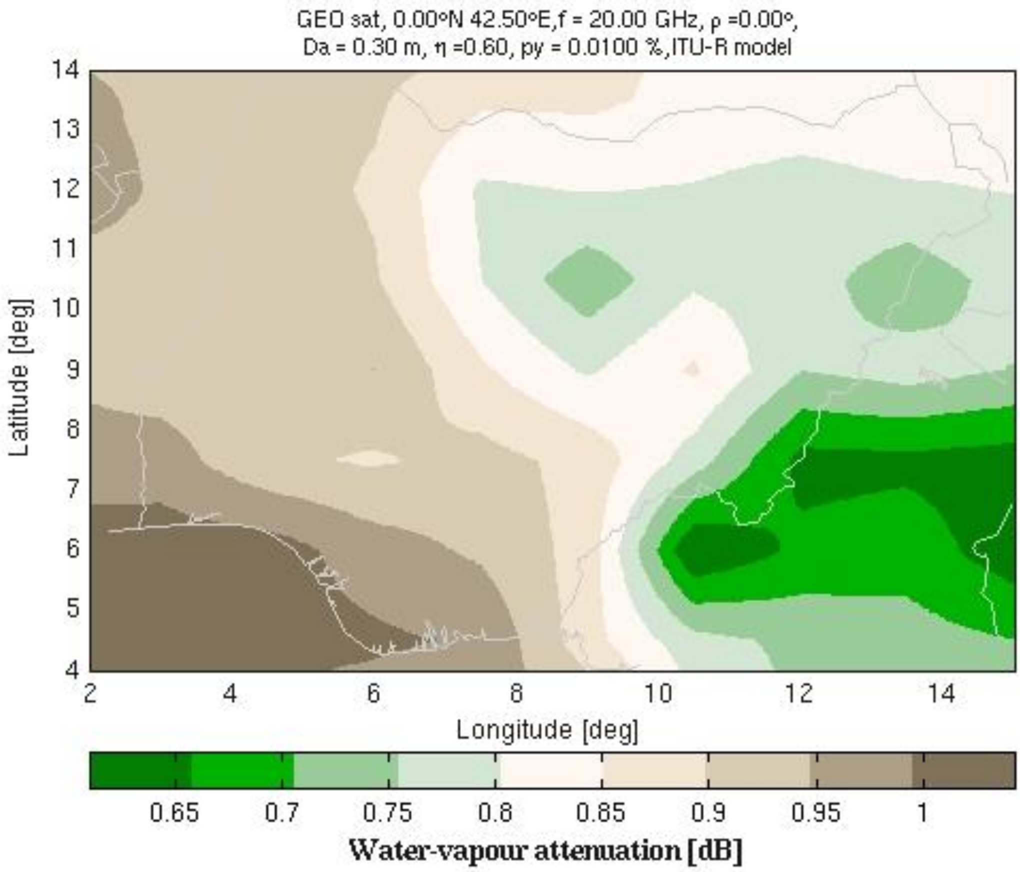

Figure 8. Contour map of water-vapour attenuation for Ka downlink (20 GHz) from NigComsat-1 at 0.01% unavailability.

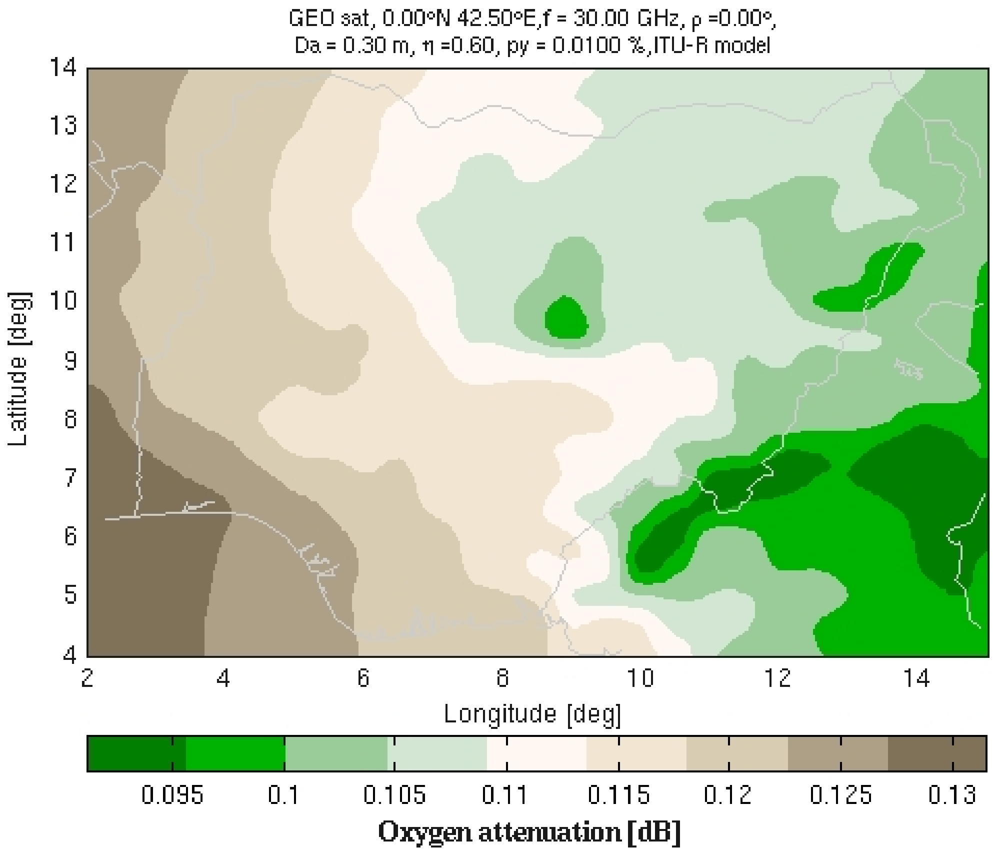

Figure 9: Contour map of oxygen attenuation for Ka uplink (30 GHz) to NigComsat-1 at 0.01% unavailability.

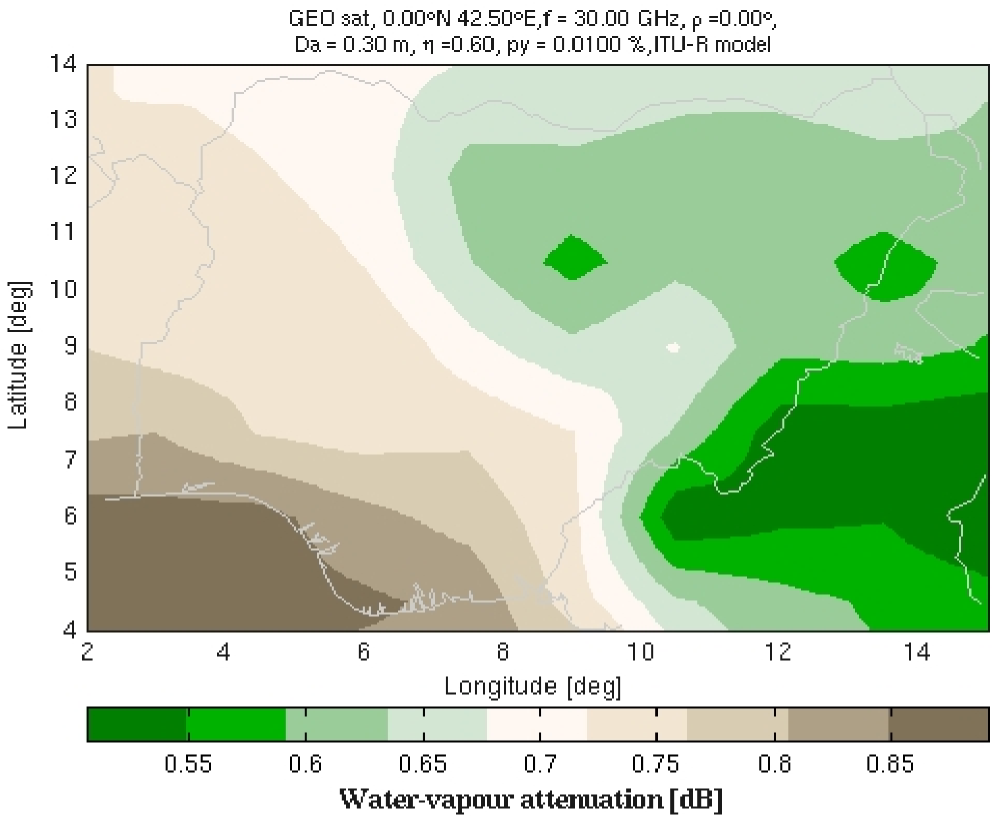

Figure 10. Contour map of water-vapour attenuation for Ka uplink (30 GHz) to NigComsat-1 at 0.01% unavailability.

5. CONCLUSION

The impact of atmospheric gases on fixed satellite communication has been investigated at Ku, Ka, and V bands for uplink and downlink frequencies at 37 observation stations in Nigeria. The data used is based on local meteorological data from recent measurements made by *AIRS* satellites between 2002 and 2009. At 0.01% unavailability the results suggest that 99.99% availability is possible at Ku bands in all the 37 stations in Nigeria. But at Ka and V bands, the South-western region and the South-southern parts of Nigeria will experience the highest signal fade between 0.7 to 1.1 dB and 0.82 to 3.1 dB respectively due to atmospheric gases even under clear sky conditions. It is thus evident that informed knowledge of gaseous attenuation engendered by Oxygen and water vapour is of ultimate importance in planning and predicting transmission and reception of radiofrequency signals on earth-space and terrestrial path. The results of this present study indicate the significance of local climatic influence on the wireless transmission of signals in general [13] and in Ku, Ka and V satellite bands in particular.

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