# STUDY OF OXYGEN AND WATER VAPOUR ATTENUATION IN WEST AFRICA

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## Abstract

Atmospheric gases such as Oxygen and water vapour attenuation has become a major concern on earth-space path at higher frequencies both uplink and down link at 0.01% unavailability of an average year. Moreover, few studies of non-rainy attenuation have been reported and the statistical analysis is still not clear most especially in West Africa. The meteorological data used in this study is obtained from Atmospheric Infrared Sounder (AIRS) satellites between 2002 and 2009, while the International Telecommunication Union Radio Propagation Recommendation (ITU-RP 676) model is used to validate and estimate gaseous attenuation for West Africa. The results show on contour map that total atmospheric absorption signal fade attenuation values at C band is between 0.015 to 0.09 dB, Ku band is 0.04 to 0.9 dB, Ka band is 0.04 to 1.4 dB and V band is 0.2 to 3.2 dB respectively for both uplink and downlink frequencies. The results also show consistent increase in attenuation due to gases are higher in the western region than in the southern part of West Africa.

Keywords: Attenuation, Satellite communication, Atmospheric gases, Impairment

## 1. INTRODUCTION

Atmospheric gases are one of major factors that affects signal impairment of satellite-to-ground and ground-to-satellite links at frequencies C-band (6/4 GHz), Ku-band (14/12 GHz), Ka-band (30/20 GHz), and V-band (50/40GHz) band (Akinwumi et al., 2016). Attenuation due to gases depends on the principle based on interaction between molecules and radiation called absorption of electromagnetic energy. At frequencies ranging from 10 GHz to 300 GHz, the electromagnetic wave propagation is affected by gaseous attenuation in the atmosphere mainly by the presence of the dry part of atmosphere (oxygen) and water vapour (Luara, 2014).

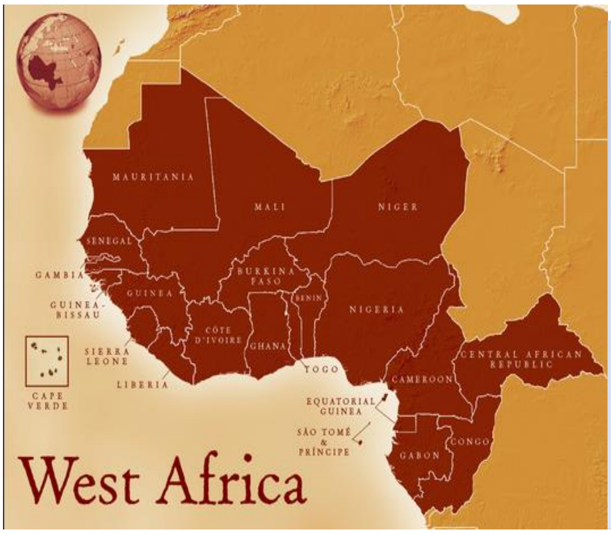
The two principal strong absorption lines at centimeters and millimeters wavelength are water vapour and Oxygen. Although atmospheric gases due to oxygen and water vapour are negligible at frequency below 10 GHz, it becomes important at higher frequency bands. The absorption of both oxygen and water vapour is significant in the determination of transmitted power and antenna gain on global broadband communication services (César, 2002). In the troposphere, radiowave propagation experiences a reduction in signal level (attenuation) due to interaction with the gaseous components in the transmission path. Therefore, it is imperative to note that when designing satellite communication system; signal degradation can be severe or sometimes minor depending on, temperature, pressure, relative humidity, frequency, and water vapor concentration (Mohamed, 2014).

The magnetic dipole moment of Oxygen is a non-polar molecule while electric dipole moment of water vapour is a polar molecule which when interacts with incident radiation cause absorption at certain frequencies 22.3, 183.3 and 323.8 GHz (Adenugba and Kolawole, 2006). At 22.3 GHz, the attenuation spectrum exhibits absorption that affects communication system operating at frequencies higher than 20 GHz which can be experienced at low elevation link (< 10º) for high percentage of time, most especially in the tropical or equatorial areas (Giovanni, 2007). The investigations into this area of study are few in West Africa and previous predictions on atmospheric gases are based on theoretical or experimental observation from temperate region data (Akinwumi et al., 2016; Ajayi et al., 1996; Adenugba, 2000; Adenugba and Kolawole, 2006).

Adenugba and Kolawole, 2006 in their study carried out in Nigeria at four different locations using Liebe's model revealed that a coastal region has higher specific attenuation than the inland region. Also from Nigeria (Omotosho and Atayero, 2010) used contour map to show that atmospheric gases impairment is very low; it ranges from 0.15 to 0.24 dB, 0.65 to 0.98 dB and 2.0 to 3.1 dB for ku-band, Ka-band V-band respectively and confirmed that southwest experiences high gas fade than the north part of the country.

Many oxygen and water vapour attenuation studies have been carried out in other tropical regions and continents with the use of theoretical and experimental approached to produced models for their regions (Ali et al., 2013; Adhikari et al., 2012; Mandeep and

Ng, 2010; Maitra and Chakraborty, 2009; Bhattacharya et al., 2007). However, only few studies have been performed in tropical region of West Africa. Hence, to produce a West African based model, ITU-R 676 propagation model (ITU, 2012) was used for the computation of this studies.



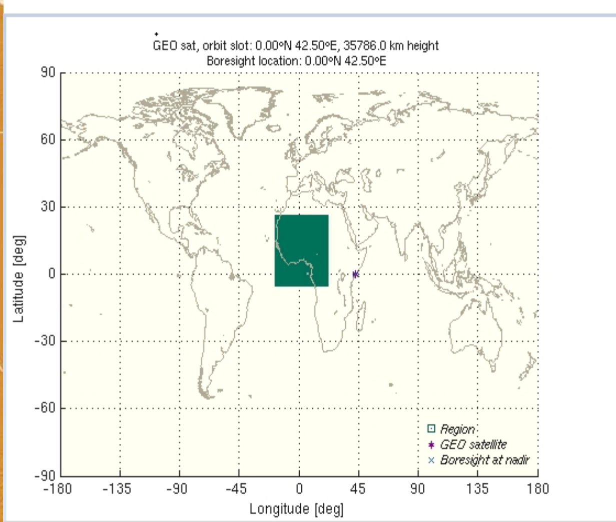




Fig. 1: Map of West Africa (www.gowestafrica.org) Fig. 2: World Map showing study area.

## 2. GASEOUS ATTENUATION DATA SOURCE

West Africa constitutes of 22 countries in Africa with population density of about 287 million (see Fig. 1). Figure 2 illustrate the AIRS meteorological Geo-satellite signal set up transmitted at longitude 42.5º E and latitude 0.00º N look angles to Nigeria. The satellite location was in Ethiopia at a height of 35,786 km, the data gathered for the period of seven years between 2002 and 2009 was used. The data obtained from ITU-R study group 3 data bank base were used to validate the observation based on indirect measurements. Daily, monthly, and yearly mean measured data of surface temperatures, pressure, and relative humidity, have been used as input parameters for the study of oxygen and water vapour attenuation loss in West Africa. The gaseous attenuation is calculated along earth-space paths at C-band (6/4), Ku-band 14/12, Ka-band (30/20) and V-band (50/40) GHz frequencies. Matlab 7.0 was used to implement the equations in the procedure of ITU-RP 676 (2012) valid for frequencies between 1GHz and 350GHz.

3. **RESULT AND DISCUSSION**

Table 1 show summary of results of clear-sky attenuation due to Oxygen and water vapour for 0.01% unavailability in an average year (53 minutes outage) for both uplink and downlink at C-band, Ku-band, Ka-band, and V-band frequencies respectively. The colour charts summarize minimum and maximum values of attenuation occurring simultaneously at all frequencies. At 99.99%-time percentage of the year is likely possible in West Africa because of low atmospheric gases attenuation values between 0.006 dB to 0.09 dB for C-band; 0.04 to 0.3 dB for Ku-band; 0.04 to 1.4 dB for Ka-band and 0.2 to 3.2 dB for V-band.

The consistency gas attenuation results show in the contour maps be a serious concern for earth-space satellite link most especially at V band which is generally higher in western part (Senegal and Mauritania) than in the southern part (Nigeria, Ghana, Cameroon e.t.c) of West Africa. The result also suggests that under clear sky conditions (i.e without rain or cloud), 100% fadeout link could be experience if a satellite communication link is designed with a low margin of about 1dB for gas attenuation at V band in tropical areas.

Figure 3-6 show typical computed oxygen and water vapour values for both uplink and down link at C-band. The absorption of oxygen dispersion show a weak attenuation values between 0.04 to 0.09 dB at 6 GHz and 4 GHz respectively (Fig. 3 and 4).

This observation may be due to constant concentration of oxygen in the troposphere. Meanwhile, water vapour resonant absorption revealed weakest attenuation in West Africa of about 0.006 to 0.016 dB at 4 GHz (see Fig.5) and 0.015 to 0.035 dB at 6 GHz (see Fig. 6).

Currently, majority of satellites communication operates at lower frequency bands in Africa and mostly in this band. However, communication systems encounter a lot of obstacles higher frequencies on the design of good receiving antennas and signal propagation through the atmosphere. For the uplink frequency results at Ku-band, it could be sited that 0.01% unavailability is possible as gas attenuation is very low close to C-band value; it ranges from 0.04 to 0.1 dB (oxygen) and 0.1 to 0.3 dB (water vapour) as shown in figure 7 and 9 respectively. Likewise, down link results display small oxygen and water vapour absorption level in the southern part with countries like Nigeria, Cameroon, Garbon and Congo been affected, reaching approximately 0.04 dB meanwhile, Senegal may experience an increase attenuation at about

0.1dB for oxygen (Fig. 8) and 0.9 dB for water vapour (Fig. 10). The western part of West Africa region may experience increase in fade of signal because of atmospheric gas attenuation particularly in under the non-rainy conditions.

At Ka-band and V-band, oxygen resonant absorption is high for uplink on earth-space path link because frequency reuse can be guarantee without any risk of interference of co-channel. It is evidence from the contour maps at 30 GHz (Fig.11) the attenuation values range from 0.1 to 0.24 dB and 1.0 to 3.2 dB at 50 GHz (Fig. 15) experience the highest signal fade. However, water vapour values range from 0.5 to 1.4 dB (Fig. 13) and 0.8 to 2.2 dB (Fig. 17) and the peak value represent zenith of absorptions resonant. Whereas, the downlink frequency of gas attenuation at Ka-band and V-band graphical illustration indicate an increase in oxygen absorption from 0.04 to 0.14 dB (Fig. 12) and 0.2 to 0.55 dB (Fig. 16) while water vapour absorption increase from 0.6 to 0.16 dB (Fig. 14) and 0.6 to 1.5 dB (Fig. 18) for Ka-band and V-band respectively.

## 4. CONCLUSION

Studies on total atmospheric absorption due to Oxygen and water vapour on the earth-space path using ITU-R 676 propagation model at C, Ku, Ka, and V bands for uplink and downlink frequencies for West Africa are discussed and presented in this paper. Monthly and yearly mean of temperature, pressure and relative humidity were used as input parameters obtained from ITU-R study group 3 data base. The gaseous attenuation data used is based on meteorological data from AIRS satellites between 2002 and 2009. At C and Ku bands results suggest that 99.99% availability is possible in West Africa because of their low signal fade between 0.04 to 0.09 dB and 0.04 to 0.1 dB respectively for oxygen and between 0.006 to 0.035 dB and 0.04 to 0.9 dB respectively for water vapour of the combination of uplink and downlink. But at Ka and V bands 0.01% unavailability is possible because of higher signal fade between 0.04 to 0.24 dB and 0.2 to 3.2 dB respectively for oxygen and 0.5 to 1.4 dB and 0.6 to 2.2 dB respectively for water vapour. Generally, gaseous attenuation has little effects at lower frequencies than other impairments like rain; however, it is major effect at higher frequencies in determining the link availability for satellite communication systems. The results in this work will help in planning and predicting transmission and reception of radio wave signals.

## ACKNOWLEDGMENT

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**TABLE 1: SUMMARY OF THE RESULT**

| BAND (GHz) | OXYGEN | | WATER VAPOUR | |
|---|---|---|---|---|
| | UPLINK (dB) | DOWNLINK (dB) | UPLINK (dB) | DOWNLINK (dB) |
| C | 0.04 - 0.09 | 0.04 - 0.09 | 0.012 - 0.09 | 0.005 - 0.016 |
| Ku | 0.04 - 0.11 | 0.04 - 0.11 | 0.1 - 0.3 | 0.05 - 0.19 |
| Ka | 0.1 - 0.26 | 0.04 - 0.15 | 0.5 - 1.45 | 0.4 - 1.8 |
| V | 1.4 - 3.4 | 0.25 - 0.6 | 0.7 - 2.2 | 0.6 - 1.5 |

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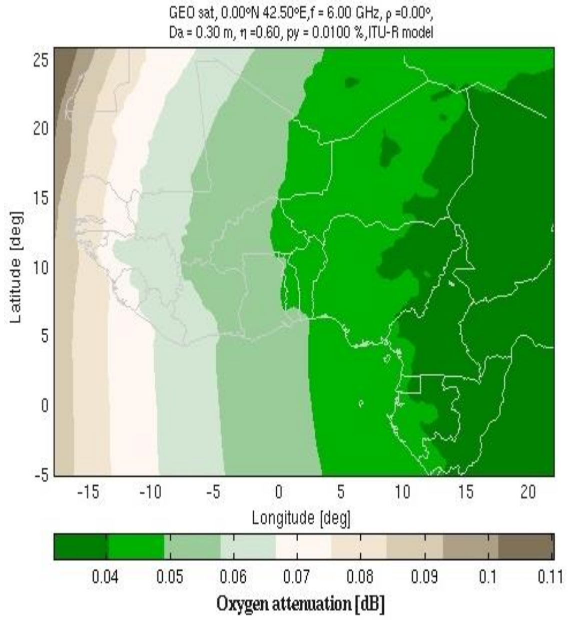


Figure 3: Contour map of oxygen attenuation for C-band uplink (6 GHz) from NigComsat-1 at 0.01% unavailability.

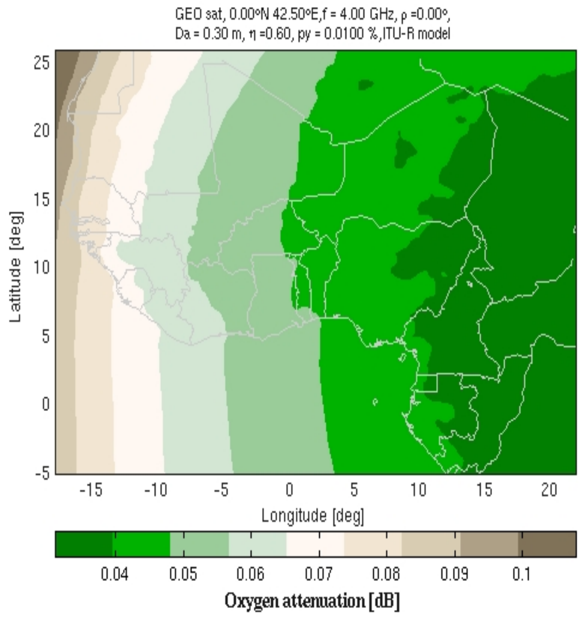


Figure 4: Contour map of oxygen attenuation for C-band downlink (4 GHz) from NigComsat-1 at 0.01% unavailability.

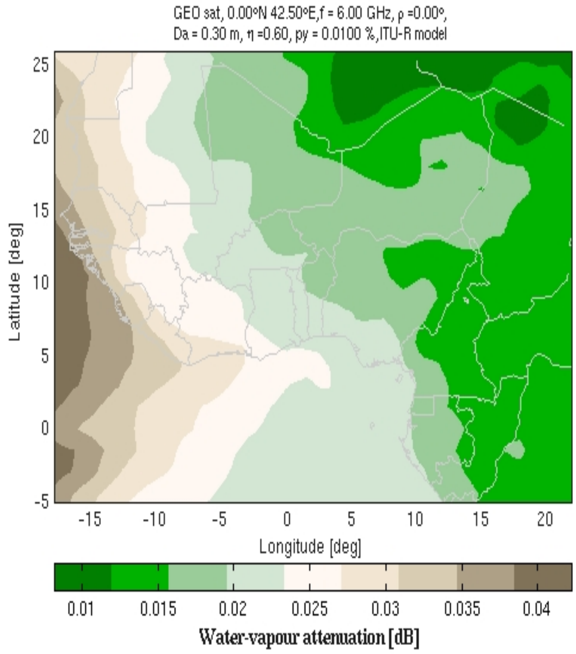


Figure 5: Contour map of water-vapour attenuation for C-band uplink (6 GHz) to NigComsat-1 at 0.01% unavailability.

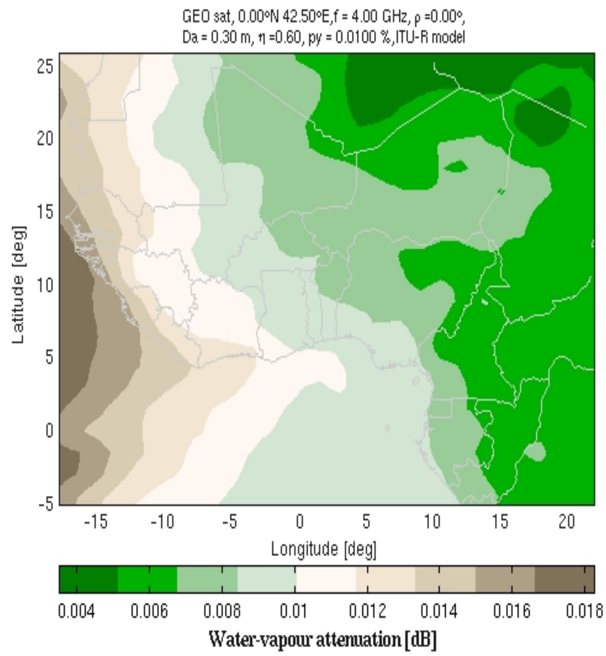


Figure 6: Contour map of water-vapour attenuation for C-band downlink (4 GHz) to NigComsat-1 at 0.01% unavailability.

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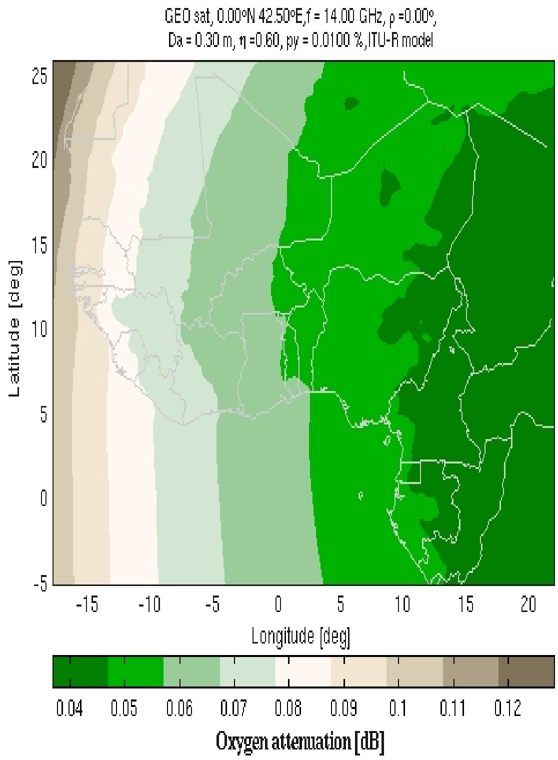


Figure 7: Contour map of oxygen attenuation for Ku-band uplink (14 GHz) from NigComsat-1 at 0.01% unavailability.

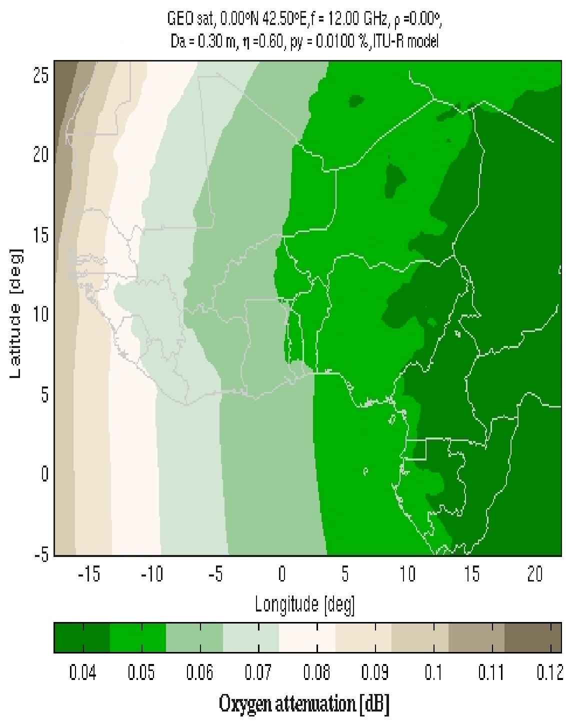


Figure 8: Contour map of oxygen attenuation for Ku-band downlink (12 GHz) from NigComsat-1 at 0.01% unavailability.

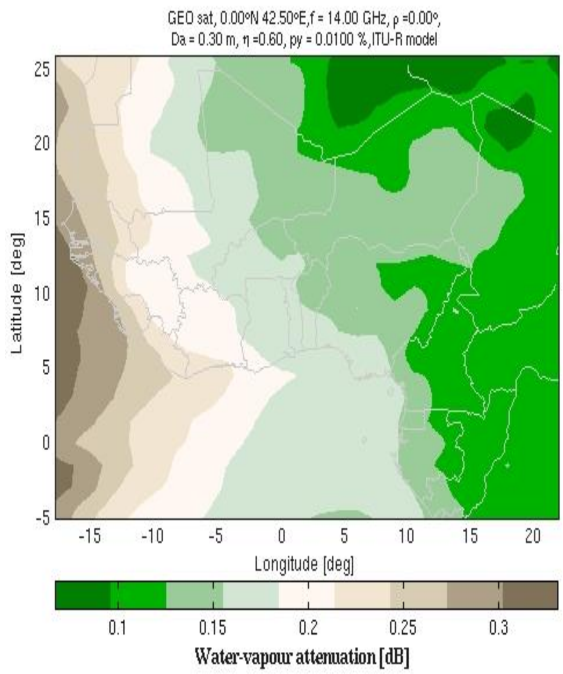


Figure 9: Contour map of water-vapour attenuation for Ku-band uplink (14 GHz) to NigComsat-1 at 0.01% unavailability.

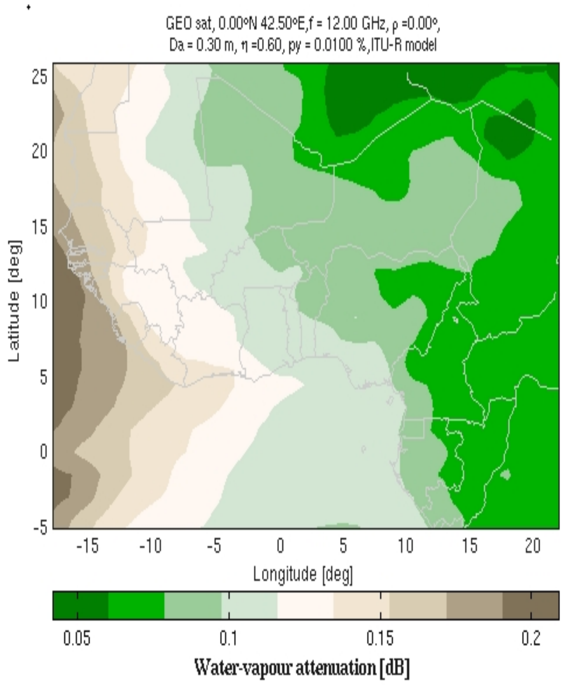


Figure 10: Contour map of water-vapour attenuation for Ku-band downlink (12 GHz) to NigComsat-1 at 0.01% unavailability.

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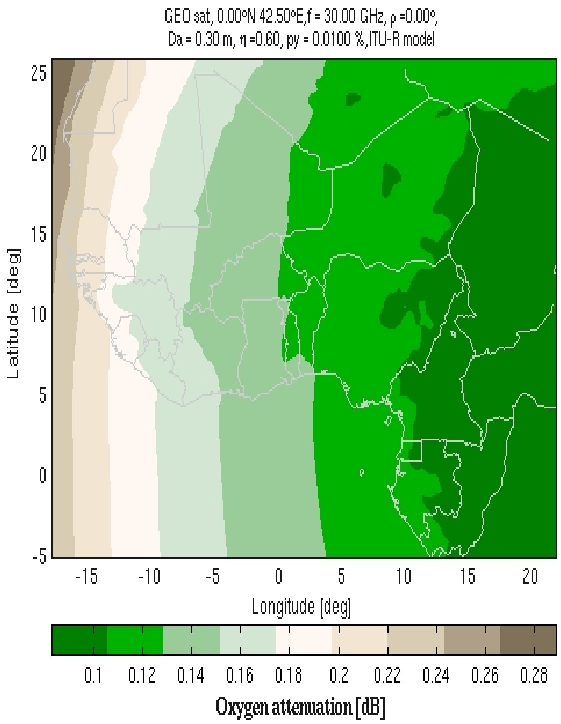


Figure 11: Contour map of oxygen attenuation for Ka-band uplink (30 GHz) from NigComsat-1 at 0.01% unavailability.

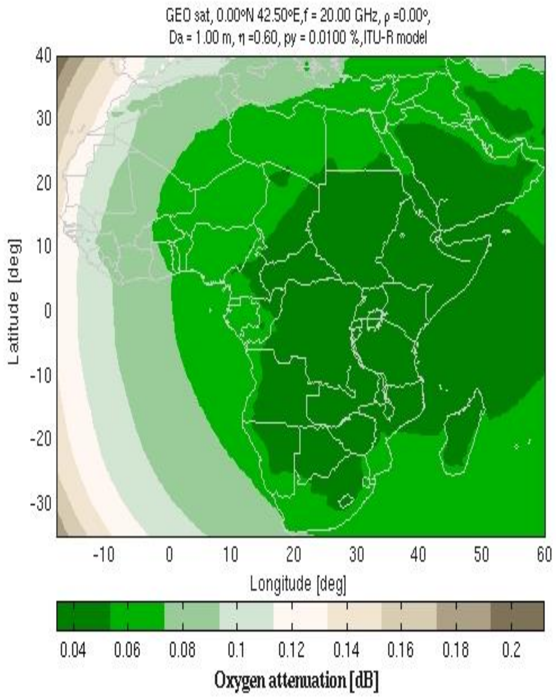


Figure 12: Contour map of oxygen attenuation for Ka-band downlink (20 GHz) from NigComsat-1 at 0.01% unavailability.

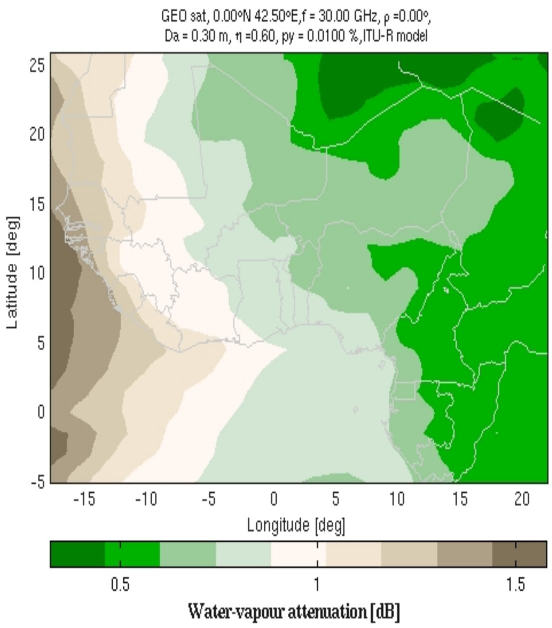


Figure 13: Contour map of water-vapour attenuation for Ka-band uplink (30 GHz) to NigComsat-1 at 0.01% unavailability.

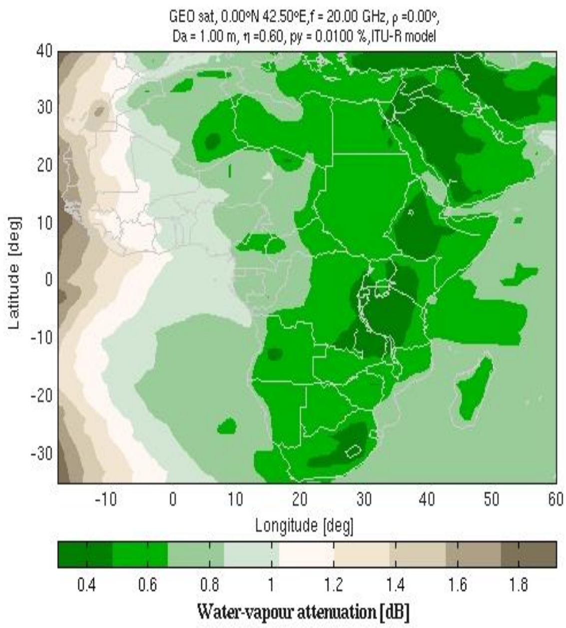


Figure 14: Contour map of water-vapour attenuation for Ka-band downlink (20 GHz) to NigComsat-1 at 0.01% unavailability.

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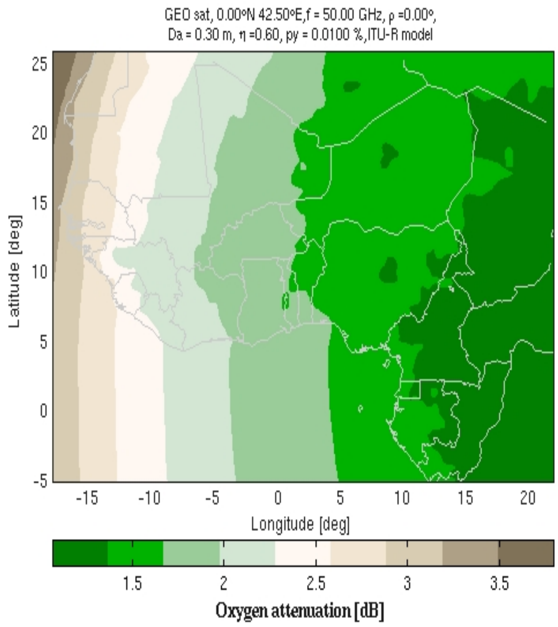


Figure 15: Contour map of oxygen attenuation for V-band uplink (50 GHz) from NigComsat-1 at 0.01% unavailability.

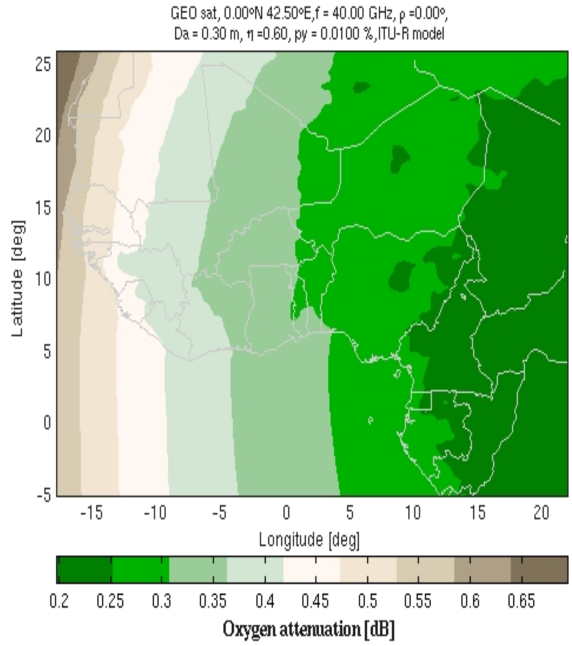


Figure 16: Contour map of oxygen attenuation for V-band downlink (40 GHz) from NigComsat-1 at 0.01% unavailability.

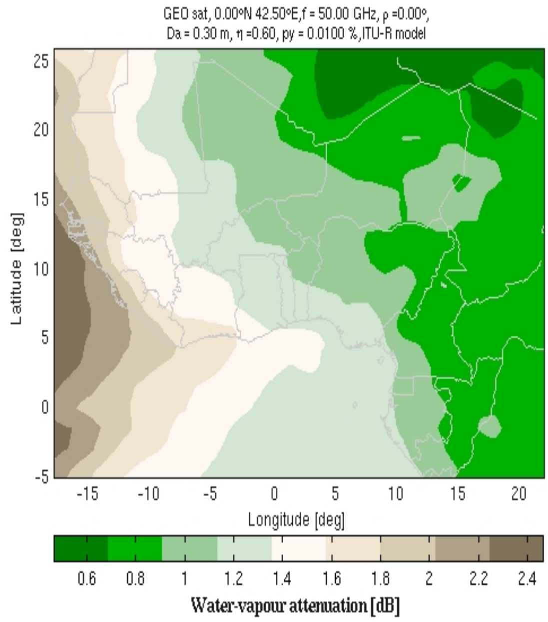


Figure 17: Contour map of water-vapour attenuation for V-band uplink (50 GHz) to NigComsat-1 at 0.01% unavailability.

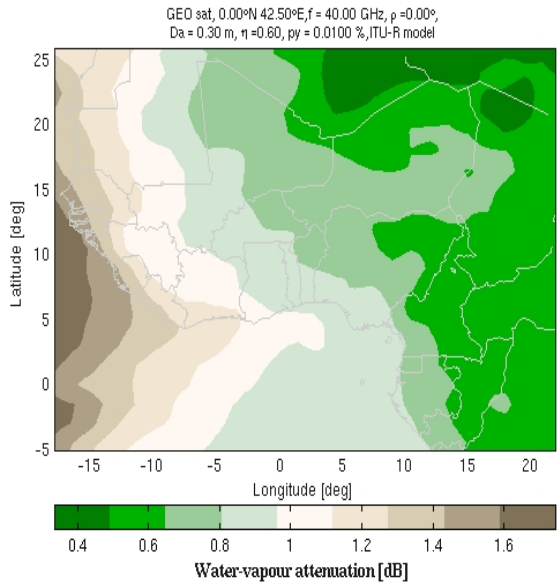


Figure 18: Contour map of water-vapour attenuation for V-band downlink (40 GHz) to NigComsat-1 at 0.01% unavailability.