Journal of Atmospheric and Solar-Terrestrial Physics 109 (2014) 1–6

Contents lists available at ScienceDirect

Journal of Atmospheric and Solar-Terrestrial Physics

journal homepage: www.elsevier.com/locate/jastp

Variation of radio field strength and radio horizon distance over three stations in Nigeria

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ARTICLE INFO

Article history:
Received 3 April 2013
Received in revised form
29 November 2013
Accepted 4 December 2013
Available online 31 December 2013

Keywords:
Radio refractivity
Radio field strength
Radio horizon distance
Clear-air propagation

ABSTRACT

In this work, we present seasonal results of radio field strength and radio horizon distance derived from the computation of surface refractivity through in-situ measurement of temperature, relative humidity and pressure across three stations (Akure, Minna and Enugu) in Nigeria. The measurements of the tropospheric parameters were made using a Davis Wireless Weather Station (Integrated Sensor Suite, ISS) installed on the ground surface at each of the stations. The study utilized data for two years of measurement (January 2008–December 2009). Results show that the values of surface refractivity were low during the dry season months and high during the wet season months. The lowest values of 323, 313 and 281 N-units were observed in February for Akure, Enugu and Minna respectively, while maximum values of 372, 375 and 365 N-units were observed in September, October and August for the respective locations. Also, the average value of field strength variability was found to be 6.67, 5.62 and 7.48 for Akure, Enugu and Minna respectively.

1. Introduction

Due to the increase in the utilization of VHF/UHF and other higher frequency bands for terrestrial and earth-space radio links, developing countries usually rely on free-air wireless systems in order to be in step with the world's digital communications development. The performance of such links in clear-air conditions depends on the radio refractivity conditions of the troposphere, which in turn depends on radio meteorological variables of air temperature, pressure and relative humidity in the area involved. The reliability of terrestrial and earth-satellite links in any location may be enhanced by proper assessment of the prevalent refractivity conditions and necessary steps to minimize link degradation and maintain signal integrity at the receiver in such location.

Radio wave propagation in free-air is generally subject to two types of losses: Free-space loss and medium loss. Free-space loss is associated with the fact that electromagnetic waves (EMW) tend to spread out as they propagate, such that in any given direction, the Poynting vector (energy transfer per unit time per unit surface area) decreases in time and space. However, energy loss due to interaction with the propagation medium is a complex and more dynamic factor (Oyedum, 2009). Some of the processes involved in EMW propagation in the atmosphere include absorption, depolarization, refraction, reflection, diffraction, and scattering; all of which largely take place in the troposphere. The degree to which any of these factors affect radio waves may depend on the frequency of the wave, the refractive index of air, as well as other local or mesoscale properties of the atmosphere. These effects are insignificant at frequencies less than 30 MHz, but they are of much importance at higher frequencies. One atmospheric property that exerts considerable control on radio propagation in the troposphere is the refractive index, n of air often referred to as radio refractivity N and which is the value by which the refractive index of air is greater than that of free-space scaled-up in parts per million. Several studies have been carried out in Nigeria on EMW medium interaction processes and the propagation implications. Examples of these studies are: Owolabi and Williams (1970), Kolawole (1980), Oyedum and Gambo (1994), Babalola (1996), Willoughby et al. (2002), Falodun and Ajewole (2006), Adediji et al. (2007), Adediji and Ajewole (2008), Adediji et al. (2011). The main objective of the present study is to appraise the clear-air performance of terrestrial radio links in Nigeria based on variability (in space and time) of signal field strength values and variability of radio horizon distance from given transmitter heights.

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http://dx.doi.org/10.1016/j.jastp.2013.12.006

2. Surface refractivity, radio field strength and radio horizon distance

Radio refractivity, N is related to radio refractive index, n (ITU-R, 2003) as;

$$N=(n-1)\times 10^6=\frac{77.6}{T}\left(P+\frac{4810\times e}{T}\right). \quad (1)$$

where T (K) is the air temperature, P (hPa) is air pressure and e (hPa) is water vapour pressure.

Eq. (1) consists of two terms; the dry term and the wet term which are given as (Cost 255 Final Report, 2002);

$$N_{dry}=\frac{77.6}{T}P. \quad (2)$$

and;

$$N_{wet}=3.3\times 10^5\frac{e}{T^2}. \quad (3)$$

The dry term contributes about 70% to the total value of refractivity while the wet term is mainly responsible for its variability (Babin et al., 1997; ITU-R, 2003).

N decreases with height exponentially, but approximates to a linear model in the lowest part of the troposphere where the gradient dN/dh=constant.

N(h) at any height, h is given by (Bean and Dutton, 1968);

$$N(h)=N_s\exp(-bh). \quad (4)$$

N_s is the surface value of refractivity while b is a factor that depends on the geographical location. The factor b may also vary with season of the year, and may be given by (Navelex 1972);

$$b=ln\frac{N_s}{N_s+\Delta N}. \quad (5)$$

ΔN is the refractivity gradient in the first kilometer above the surface. Surface refractivity correlates highly with radio field strength, especially at the VHF bands. In the frequency range 30–300 MHz, a factor of 0.2 dB change in field strength may be adopted for every unit change in N_s (CCIR, 1959; Owolabi and Williams, 1970). Using N_s values obtained in a given calendar month, maximum ($N_{s(\mathrm{MAX})}$), and minimum ($N_{s(\mathrm{MIN})}$) values of N_s are determined; from which the monthly range is obtained as;

$$Monthly\ range=N_{s(MAX)}-N_{s(MIN)}. \quad (6)$$

Thus, an assessment of field strength variability (FSV) in a given location is explored from monthly ranges of N_s using the relation;

$$FSV=(N_{s(MAX)}-N_{s(MIN)})\times 0.2\ \ dB. \quad (7)$$

Near the surface (where refractivity gradient is approximately constant), the effective earth's radius model is adequate for low-elevation terrestrial radio propagation studies. Under such conditions the radio horizon becomes an important parameter in determining the coverage area of a terrestrial radio link, depending on the transmitter height. The radio horizon distance, d_{RH} is theoretically the maximum distance an unobstructed radio signal will travel from the transmitter before grazing the surface, and for a receiver to be effective, it must be installed within that distance. Due to atmospheric refraction, radio horizon d_{RH} extends longer than the optical horizon d_{OH} (Fig. 1). Radio horizon distance, d_{RH} depends on the transmitter height h_{t} and the value of N_s at the location, and may be given by Bean and Dutton (1968);

$$d_{\mathrm{RH}}=\sqrt{2kah_t}=\sqrt{2a_eh_t}. \quad (8)$$

where k is earth's radius factor, a is earth's radius and a_e is the equivalent earth's radius (Hall, 1979). The effective earth radius,

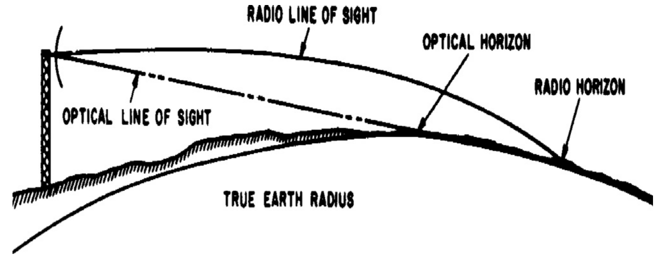

Fig. 1. Relationship between optical and radio horizon distances (Hall, 1991).

k, may be given as (Bean and Dutton, 1968);

$$k=(1+a\Delta N\times 10^{-6})^{-1}. \quad (9)$$

Kolawole (1980) obtained ΔN for Nigeria as;

$$\Delta N=-1.46\exp(0.00918N_s). \quad (10)$$

which gives a_e as

$$a_e=ka=(1+a\Delta N\times 10^{-6})^{-1}$$
$$a=[1+a(-1.46\exp(0.00981N_s)\times 10^{-6})]^{-1}a. \quad (11)$$

3. Climatic characteristics of Nigeria

Nigeria lies between latitudes 4°N and 14°N and longitudes 3°E and 15°E, covering an area of about 924,000 km^2. It is bordered by Cameroon to the East, Benin Republic to the West, Niger Republic to the North and to the South by about 800 km stretch of Atlantic coastline that forms the Eastern sector of the gulf of Guinea, partly in the Bight of Benin (Fig. 2). The climate is broadly equatorial and tropical continental. Movement of the Inter Tropical Discontinuity (ITD) complemented by aspects of ocean-atmosphere coupling make Nigeria's climate truly tropical with generally high temperatures ranging from 24 to 27 °C and annual mean temperature of 27 °C in the tropical rainforest down south but higher mean value in the sub-Sahel up north. Tropical maritime air mass (South-Westerlies) and tropical continental air mass (North-Easterlies) constitute the main wind system over the country. While the former fills the troposphere with moisture in the wet season, the latter brings a lot of Harmattan dust from the Sahara during the dry season.

The Northern part of Nigeria experiences a long dry season (October–mid May) followed by a short rainy season (June–September), during which annual mean is about 50 cm. However, the Southern part experiences a long rainy season (March–October) with maximum in June/July with a short dry period of about 2–3 weeks in August and a long dry season from mid October to early March. Annual mean along the South-Eastern Atlantic coast is about 400 cm. These rainfall regimes endow Nigeria with two broad vegetation belts that comprise the Forest to the South and the Savanna to the North (Umoh, 2000). The climate of Akure (07°09′N, 05°07′E) represents tropical maritime, Enugu (06°52′N, 07°30′E) is tropical rainforest/savannah and Minna (09°37′N, 06°30′E) represents tropical savannah. The three locations were chosen as a representation of the climatic regions of Nigeria.

4. Method of analysis

Surface values of pressure (hPa), temperature (K) and relative humidity (%) were extracted from the Davis Automatic Weather Station, Vantage Pro2 Integrated Sensor Suite (ISS) installed at the ground surface at the three locations considered for this study. The temperature and relative humidity values were used to calculate the water vapour pressure e, (hPa). The results were then used in