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Case Study of Secondary Radioclimatic Variables on Radio Signals at the Troposhere in Nsukka, Nigeria

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Abstract: ***In the present study, the effect of secondary Radioclimatic variables on radio signals at the troposphere in Nsukka, Nigeria was investigated. It is generally known that for a reasonable prediction for radioclimatic study to be made, a reliable radio propagation data which could be primary or secondary is required. The secondary data can be estimated from a relevant primary data which include; temperature, pressure, humidity and water vapour pressure. The effect of the secondary radioclimatic data; refractivity (N), and refractive index (n) in the study area indicate that the values of the radio refractivity and refractive index were increased. The result also, show that the k-factor (effective earth's radius) values for the months (August 2013 – July 2014) were at the range of 1.555 – 1.653, which is above the global standard value of 1.333. These values strongly suggest that super-refraction effects are possible in the study area, leading to possible distortion of wireless communication signals.***

Keywords: troposphere, Radioclimatic variables, , surface refractivity, k-factor, Nsukka.

1. Introduction

The electron concentration in the ionosphere is significantly modified by the impact of solar activity on the tropospheric radio refractivity, resulting in the perturbation of electromagnetic wave propagation in the troposphere. These perturbations could result in the variations in the refractive index in the troposphere. The importance of the knowledge of refractive index in our communication designs cannot be overstressed, hence when designing the line of sight communication gadgets, a thorough knowledge of the refractive index of the troposphere is needed for the execution of a successful and functioning operational system. It has been established [1] that a change in the refractive index in the lower atmosphere generally has an effect on frequencies > 30 MHz, and more significant at frequencies > 100 MHz. The propagation of electromagnetic waves around the earth is influenced by the properties of the earth and the atmosphere. The earth is an inhomogeneous body whose electromagnetic properties vary considerably as we go from one point to another. The impinging electromagnetic waves from the outer space to the troposphere and quantum mechanical resonances at some particular bands of frequency do cause some significant degree of polarization of the molecules, resulting in the modifications of the tropospheric refractive index. According to the literature [2], the frequency range of the millimeter wave band are usually not affected by molecular polarization but rather, molecular resonance generally depends on frequency, and the refractive index are mostly dispersive for frequency range ≤ 50 GHz.

It is generally known that the earth atmosphere is characterised by the changes in a number of meteorological parameters which includes; pressure, temperature, relative humidity, wind speed and direction, precipitations, evaporation, etc, and that these parameters show variations due to geographic position, season, time of the day and the solar cycle. Research done by Adeokun, 1978 [3], indicate that the degree of accuracy in the measurement of the variations of these atmospheric parameters is largely dependent on the care exerted by the experimenter/observer, coupled with the sensitivity of the equipment used in the experiment. Some research groups [4], noted that the performance of microwave links depends mostly on the quality of the propagation of electromagnetic waves between the transmitter and receiver. Afullo and Odedina [5], opined that the quality of the propagation depends on the appropriate procedure required for proper planning of terrestrial and earth-space radio links. These research groups (Afullo and Odedina) [5], further stressed that this is important for assessing the refractivity effects on radio signals within the troposphere.

In this study, the effect of these secondary Radioclimatic variables on communication signals is investigated. The study area (Nsukka) is located at latitude 6^o 45N and longitude 7^o 30E, South –Eastern Nigeria [6]. The period of investigation in this research (August 2013 – July 2014), cuts across the two major seasons (wet and dry) in Nigeria.

2. Literature Review

2.1. Layers of the Atmosphere

The earth's atmosphere is broadly divided into five different layers which include: troposphere which extends from 0-17 km, stratosphere which extends from 17 km to 50 km, mesosphere which extends from 50 km to 90 km, ionosphere which occupies from 90 km to 350 km, and the magnetosphere which is from 350 km to 900 km [7]. However, for the purpose of this research, the activities within the troposphere was investigated.

2.2 Troposphere

Fig. 1 gives the position of the troposphere in the schematic of the layers of the earth's atmosphere as contained in the literature [8]. The troposphere is the lowest layer of the earth's atmosphere and generally extends from the earth surface i.e water level to about a distance of 17 km up in the atmosphere. It is within this layer that the clouds and weather takes place. According to the literature [9], it has been established that temperature decreases with altitude within this layer (the troposphere). However, it is pertinent to note that between the troposphere and the stratosphere, there is a transition layer generally referred to as the boundary or buffer zone known as the tropopause. The behaviour of this layer differs from the troposphere in that the temperature remain stable with increasing altitude.

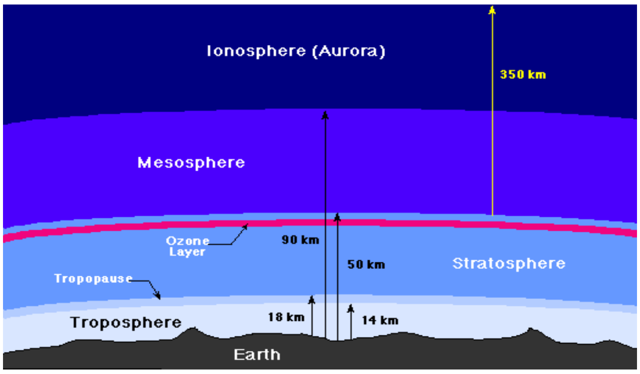

Figure 1: Layers of the atmosphere.

Source: *http://csep10.phys.utk.edu/astr161/lect/earth/atmosphere.html*

2.3. Atmospheric Refraction

Atmospheric refraction is simply the deviation of light or other electromagnetic waves from a straight line as it transverses the atmosphere as a result of the variation of air density with altitude. Typical consequences of atmospheric refraction are commonly observed as mirage. In general, the magnitude of atmospheric refraction depends on temperature, relative humidity, and pressure [10-11]. The consequence of atmospheric refraction can be more damaging especially under the conditions of inhomogeneous atmosphere e.g. when there is turbulence in the air. It has been established that such condition is mostly the cause of twinkling of the stars and deformation of the shape of the sun at sunset and at sunrise.

2.4 Refractive Index of the Troposphere

In general, radio wave propagation in the troposphere is mostly considered to take place within a non-ionized medium. Since the troposphere is taken to be a dielectric medium in radio propagation study, and it is in the troposphere that most of the meteorological phenomena such as wind and rain which depends mostly on pressure, relative humidity and temperature take place. Moreso, the variations of the refractive index are small but plays a vital role in radio wave propagation. Accordingly, the refractive index n is defined as [12],

$$n = (\varepsilon\mu)^{0.5} \qquad (1)$$

In equation 1, ε is the dielectric constant, and μ is the relative permeability of the medium. The difference between the value of refractive index in the troposphere (n ≈ 1.00003), and in free space (n = 1.0) is not much hence the variation is more conveniently defined by a new parameter called "refractivity, N", given in the literature as [11];

$$N = \langle n - 1 \rangle \, x \, 10^{-6} \qquad (2)$$

Equation 2 is the excess over unity of the refractive index expressed in millionths, hence at the surface where n = 1.000314, the value of N is 314 N-unit [11]. Ayatunji et al [13] noted that the "radio refractivity N, is a measure of deviation of refractive index n of air from unity which is scaled-up in parts per million to obtain more amenable figures".

3. Research Methodology

In the present investigation, indirect means of measuring the atmospheric profiles was utilised using the fixed measuring method. In this approach, a tower equipped with meteorological measuring instrument at ground level and also, a sensor was fixed at surface level at center for basic space science (CBSS) at the University of Nigeria, Nsukka was used. The instrument is a wireless vantage pro 2 automatic weather station which consists of integrated sensor suit (ISS), wireless console with a storage device known as the data logger and laptop computer for data downloading. Fig. 2 gives a picture of the complete set of wireless Davis Vantage Pro2 instrument installed at CBSS, University of Nigeria, Nsukka observatory.

Figure 2: Picture of Davis Wireless Vantage Pro2 and Fan-Aspirated Radiation Shield (model 6153).

The model 6153 consists of the Vantage Pro2 console/receiver, integrated sensor suite (ISS), and mounting hardware. The ISS consists of a rain collector, temperature and humidity sensors, anemometer, 12 m anemometer cable, and a solar panel. Temperature and humidity sensors were enclosed in patented solar-powered 24-hour fan-aspirated radiation shield.

The method of measurement was done by by fixing the integrated sensor suit (ISS) at surface level at the centre for basic space science (CBSS) mast in Nsukka for the measurement of the weather parameters in the study area. This method adopted herein, provides an accurate measurement of parameters required for the estimation of refractive index, effective earth radius (k-factor) and radio refractivity for the research periods (August 2013 – July 2014). By this method the sensor was positioned upward on the tower while the console is positioned on the ground. The signals from the sensor were transmitted to the receiver (console) by radio waves. The data is stored on the data logger attached to the console located on the ground from which the data are then copied to the computer. The in-situ measurements of meteorological parameters of temperature in (^{o}c), Pressure in hpa and relative humidity in percentage from the data collected for 24 hours each day from zero hour to 23:00 hours local time at intervals of 30 minutes from August 2013 to July 2014 were recorded. However, the data covers both wet and dry seasons in Nsukka region. In Nigeria, dry season is mainly from November to March while the wet season starts from April to October.

4. Results and Discussion

4.1 Surface refractivity

The atmospheric parameters mostly used to determine the surface refractivity are; temperature, pressure and relative humidity. According to the literature [14] the surface refractivity or refractivity N, and other meteorological parameters such as the atmospheric pressure, temperature, vapor pressure are related by the equation given as;

$$N\frac{77.6}{T}\left(P+4810\frac{\ell}{T}\right)=77.6\frac{P}{T}+\left(3.732x10^5\,\frac{\ell}{T^2}\right) \quad (3)$$

In equation 3, N retains its meanings, P is the barometric pressure in millibars, ℓ is the saturated vapour pressure in millibars, and T is the absolute temperature in Kelvin.

The changing nature of the atmosphere causes the refractive index of the troposphere to vary as the height increases from sea level [15]. It is widely understood that the refractivity of the troposphere is divided into two compositions; the dry and the wet composition. The first term in both sides of equation 3 represent the dry term while the second term represent the wet term. The dry term is usually proportional to the density of the gas molecules in the atmosphere and changes with their distribution. Moreover, the relationship between the saturated vapor pressure and relative humidity is used to calculate the water vapor pressure using the expression given in the literature [13]:

$$e_s = \frac{100\,e}{H} \quad (4)$$

In equation 4, e_s is the saturated vapor pressure (hpa), and e is the partial pressure of water vapor in millibars, and H is the relative humidity in (%). Also, it has been established [13] that e_s can be expressed in the relationship with temperature as;

$$e_s = 6.1121\exp\left(\frac{17.592\,t}{t + 240.97}\right) \quad (5)$$

where t is the temperature in degree Celsius (^{0}C) and e_s is the saturated vapor pressure (hpa) at the temperature t (^{o}C).

The data obtained from the computations using equation 3 was used to plot the variations of surface refractivity, N_S, with refractive index, n. Fig. 3 gives that variations of the surface refractivity, N_S, with refractive index, n. As indicated in the plot (Fig. 3), the surface refractivity exhibited a linear fit with the refractive index.

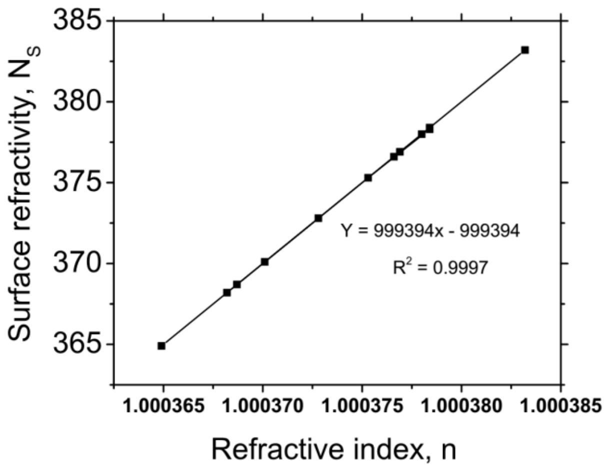

Figure 3: Variation of surface refractivity with refractive index

Fig. 4 shows the change in temperature and humidity with the refractive index, n. As shown in Fig. 4, there is a relatively increasing distribution of humidity with the refractive index between temperature range of 70 ^{o}C to 90 ^{o}C, and then decreased therafter, while a sparingly constant change was observed for the temperature variation. Isikwue et al [16] observed similar trend for same/different variables.

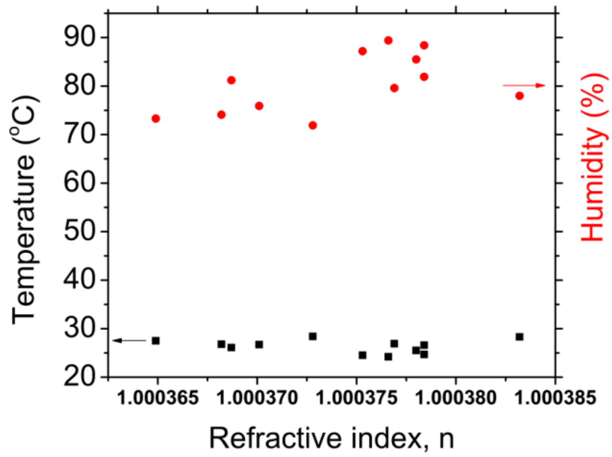

Figure 4: Variation of temperature and humidity with refractive index.

Fig. 5 shows the change in water vapour pressure, e_s, with the refractive index, n. As shown in Fig. 5, the variation exhibited scatter behaviour with refractive index. This behaviour was attributed to the prevailing seasons and weather conditions in the study area.

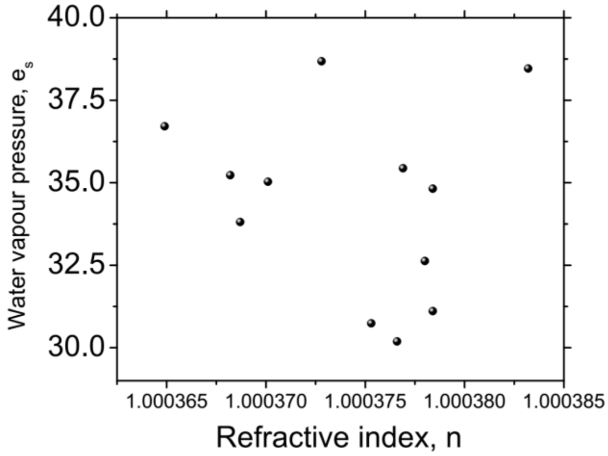

Figure 5: Change of water vapour with refractive index.

4.2 k-factor

Fig. 6. show the change of k-factor with surface refractivity. According to Freeman [17], to determine the k-factor, one need to know the relationship between the radius of curvature of the ray, ρ, and the change of refractivity, N, with height, h, if v is the velocity of wave propagation. The k-factor was determined using the relation discussed in the literature [18-19] hence:

$$k = \frac{1}{1 - a/\rho} \qquad (6)$$

Where a is the earth radius given as 6375 km and ρ is further related to the surface refractivity as;

$$\rho = \left(\frac{a}{1 - 0.04665\, e^{0.005577 N_S}} \right) \qquad (7)$$

where a and Ns retains their usual meanings.

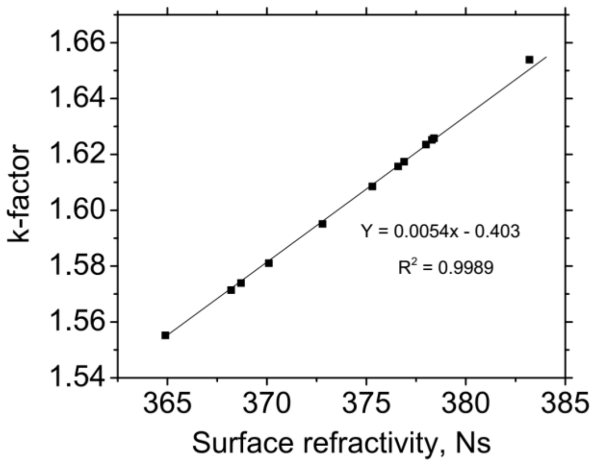

Figure 6: Change of k-factor with surface refractivity

The effective earth radius (k-factor) was observed to show a linear fit with surface refractivity. The values of the k-factor were above the global standard value of 1.333. This is an indication that signal distortion could be observed in the study area.

5. Conclusion

In this study, the In-Situ measurement of temperature, pressure and relative humidity (primary radiocilmatic data) was carried out at Nsukka, Nigeria between August 2013 to July 2014. The data from these station was employed to determine the refractivity (N), refractive index (n) and k-factor. The k-factor determined from the measurement were used to evaluate the propagation conditions over Nsukka and its implication on microwave communication. The result of the k-factor show a monthly variation from 1.555- 1.653, indicating that signal distortion is possibel in the study area since the k-factor value is > 1.333.

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