3rd International Engineering Conference (IEC 2019)
Federal University of Technology, Minna, Nigeria

RADIO REFRACTIVE INDEX AND REFRACTIVE INDEX GRADIENTS VARIATION IN A TROPICAL ENVIRONMENT

I.M. TUKUR, K.C. IGWE and J.O. EICHIE.
Department of Physics, Federal University of Technology, Minna.
Email: ishaqmtukur@yahoo.com, +2348032075689

ABSTRACT
This paper investigates variation of radio refractivity with related weather parameters and refractivity gradient with altitude. Three years (2013-2015) upper air atmospheric data of temperature, pressure and relative humidity for Abuja were obtained from the Nigerian Meteorological Agency (NIMET). The result shows that temperature, pressure and relative humidity decreases with increasing altitude. Radio refractivity values over Abuja are observed to be decreasing with increasing altitude and values in the rainy season are higher than dry season with a maximum of 344.1 N-units recorded in August and a minimum 277.5 N-units recorded in January. The average refractivity gradient for both dry and wet months is -30.6 N-units/km and the average k-factor as 1.25 which is in agreement with the condition of Sub-refraction.

Keywords: *Refractivity, Refractivity Gradient, K-factor*

1 INTRODUCTION

Radio refractivity is the ratio of the radio wave propagation velocity in free space to its velocity in a specified medium. Radio wave propagation is determined by changes in the radio refractive index of air in the troposphere. The troposphere is the layer of the atmosphere that is most closely related to human life and it is the region of all weather on earth and also the lowest of all the layers, extending from the earth surface to an altitude of about 10km at the north poles and 17km at the equator (Hall, 1979). A change in the magnitude of radio refractive index of the troposphere causes the path of the propagating radio waves to be curved.

Electromagnetic waves propagation in the troposphere are influenced mainly by different components that make up the atmosphere due to variations of some major atmospheric weather variables such as atmospheric temperature, pressure and relative humidity in the troposphere (Ukhurebor, *et al*., 2018: Ukhurebor and Azi, 2018: Agbo, *et al*., 2013). Variations in these atmospheric weather variables cause the refractive index of air in the troposphere to differ from place to place (Ukhurebor, *et al*., 2018).

Radio refractivity serves as a function in determining the quality of UHF, VHF and SHF signals for proper design of their communication station and the planning of good terrestrial radio link over a region (Chukwnike & Chinelo, 2016). Surface and elevated refractivity data are often required by radio engineers to accurately predict electromagnetic wave signals and characterization of radio channels.

In the troposphere, the vertical refractivity gradient serves as an important parameter in estimating path clearance and propagation effects such as sub-refraction, super-refraction or ducting (Adediji and Ajewole, 2008). During ducting condition, atmospheric refractive index decreases sharply with height over a large horizontal area, radio waves can be trapped and forced to follow the earth`s curvature, thus experiencing low-loss propagation over long distance, while in super-refraction, radio waves are bend towards the earth. In sub-refractive condition, refractivity increases with increasing altitude, the radio waves moves away from the earth's surface and the line of sight range and the range of propagation decreases accordingly (Akpootu and Iliyasu, 2017).

2 METHODOLOGY

Radiosonde data of daily temperature, pressure and relative humidity for three years (2013-2015) were obtained from the Nigerian Meteorological Agency (NIMET) headquarters in Abuja.

Abuja, the capital city of Nigeria, located at coordinates 9.01 N and 7.27 E in the guinea savannah of northern climate region of the country and at about 370m above mean sea level. Abuja experiences three weather conditions of a warm, humid rainy season and extremely dry weather conditions.

The daily measured upper atmospheric data of temperature, pressure, relative humidity and height were averaged to get the monthly mean data and the monthly values were also averaged to get the yearly data. These were analyzed to evaluate the monthly and yearly radio refractivity variations. Starting from the relationship between water vapour pressure and relative humidity as written in equation 1.

$$e = \frac{H\,es}{100} \quad (1)$$

Where

H = Relative Humidity, es = Saturated Vapour Pressure

$$e_s = a \exp\left(\frac{b\,t}{t+c}\right) \quad (2)$$

t: Celsius temperature (°C) and a, b, c are coefficients given as a= 6.1121, b= 17.502, c= 240.97 for water and a = 6.1115, b = 22.452, c = 272.55 for ice.

(Valid between –20° to +50°, with an accuracy of ± 0.20% for water)

(Valid between –50° to 0°, with an accuracy of ± 0.20% for ice)

The refractivity index n, of air is measured by refractivity N in a relation given by (Agbo, *et al*., 2013)

$$N = (n-1)10^6 \quad (3)$$

Refractivity is a dimensionless quantity and ranges from 250 and 400N-units. As recommended by (ITU-R, 1997) N is given as:

$$N = \frac{77.6}{T}\left(P + 4810\frac{e}{T}\right) = N_{dry} + N_{wet} \quad (4)$$

Where Ndry and Nwet according to (Hall, 1979) represent dry and wet component of refractivity and is given as

$$N_{dry} = 77.6\frac{P}{T} \quad (5)$$

$$N_{wet} = 3.73\times10^5\frac{e}{T2} \quad (6)$$

Where T is the absolute temperature (K) and P is the atmospheric pressure (hpa).

The refractivity gradient or vertical gradient of refractive index as recommended by (ITU-R, 1997) is expressed as:

$$G = \frac{N1-N2}{h1-h2} \quad (7)$$

Where N_1 and N_2 are radio refractivity values at heights h_1 and h_2 respectively.

According to Adediji and Ajewole,, (2008) propagation effects such as sub-refraction, super-refraction and ducting are characterize according to the following criteria.

$$\frac{dN}{dh} > -40 \quad \text{Called Sub-refraction} \quad (8)$$

$$\frac{dN}{dh} < -40 \quad \text{Called Super-refraction} \quad (9)$$

$$\frac{dN}{dh} < -157 \quad \text{Called Ducting} \quad (10)$$

Effective earth radius factor K is use to classify propagation effects such as normal refraction, sub refraction, super refraction and ducting.

$$K \approx \left[1 + \frac{\left(\frac{dN}{dh}\right)}{157}\right]^{-1} \quad (11)$$

When, $\frac{dN}{dh} = \frac{4}{3}$ Normal refraction (12)

$\frac{4}{3} > k > 0$ Sub-refraction (13)

$\infty > K > \frac{4}{3}$ Super-refraction (14)

3 RESULTS AND DISCUSSION

3.1 VARIATIONS OF WEATHER PARAMETERS WITH ALTITUDE

Figures 1 and 2 show variation of temperature (T), pressure (P) and relative humidity (RH) with altitude for January and August 2013. From the graphs, temperature in each of the two months period is seen to be decreasing with increasing altitude. In the two months under study, temperature inversions are observed at a height of about 18.6km which increases and continue increasing further. This corroborated the fact that temperature in the stratosphere usually increases with increasing height. From the two figures, it is also observed that January recorded the highest temperature as compared with August, with maximum of 29 ^{0}C at the height of 829 m. August on the other hand recorded a temperature of 22.2 ^{0}C at approximately the same height.

Air pressure also showed a decrease with increasing altitude as observed in the graphs. The result is in agreement with the facts that since most of the atmospheric molecules are held close to the earth's surface by the force of gravity, and then pressure decreases rapidly at first, then more slowly at higher levels.

Similarly, it is observed from the figures that relative humidity in both January and August shows a decrease with increasing altitude. However, an increase is observed at an altitude of about 3.2km in January and 5.9km in August which begin to decrease until it tends to zero. Due to the availability of large moisture contents expected during the raining season. August which is a rainy month, recorded the highest relative humidity with a value of 80.1% at pressure height of about 925hpa as compared with January having a value of 35%.

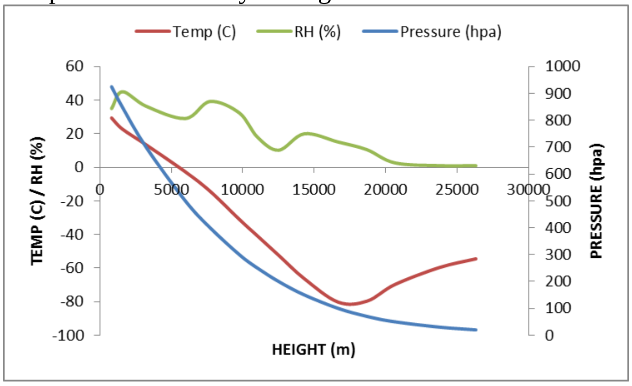

Figure 1: Variation of weather parameters with height for a typical dry month (January, 2013).

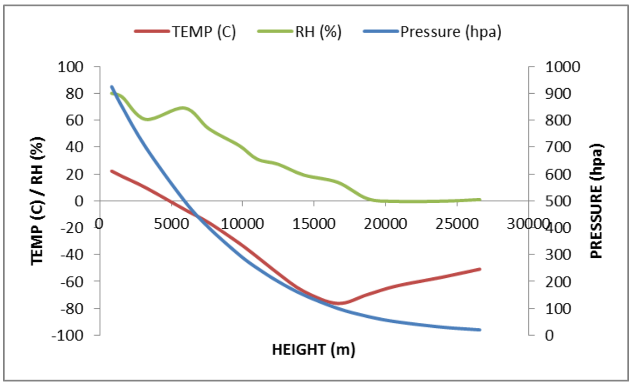

Figure 2: Variation of weather parameters with height for a typical wet month (August, 2013).

3.2 VARIATIONS OF REFRACTIVITY WITH HEIGHT

Figures 3 and 4 depict the variation of refractivity with altitude for January and August 2014. The graphs show that refractivity over Abuja in both January and August decreases with increasing altitude. Radio refractivity in August is observed to be decreasing from a maximum value of about 336.6 N-units at 830m to a minimum value of 7.0 N-units at about 26.6km, while in the month of January, it decreases from 287.9 N-units to 7.1 N-units at the heights of about 815 m and 26.3 km respectively.

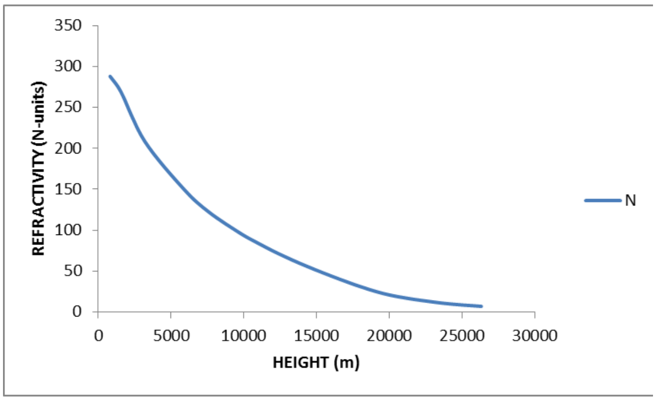

Figure 3: Variation of refractivity with height for January 2014

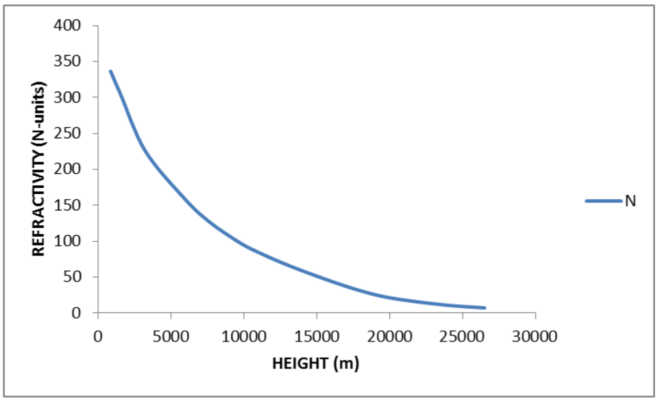

Figure 4: Variation of refractivity with height for August 2014

3.3 DRY AND WET SEASON VARIATION OF REFRACTIVITY AT A HEIGHT OF 1KM

Figures 5 and 6 show refractivity values for dry and wet season months for the year 2015. The refractivity values are seen to be lower in the dry season months (November – March) as compared to wet season months (April – October) and this is a consequence of less moisture content during the dry month period because of influx of large quantity of north easterly winds. The values are higher during the wet months due to availability of large amount of moisture content which is as a result of influx of large quantity of south westerly winds. The values in the wet months show an increase from April-October in the range of 307.9 N-units to 344.1 N-units. In the dry season months, the values are seen to increase from January-December in the range of 272.5 N-units to 306.8 N-units. In general, it is observed that refractivity values in the year 2015 ranges from the lowest value of 272.5N-units in January in the wet months to its highest value of 344.1N-units in October in the wet months. This is in agreement with the work of Igwe and Adimula (2009) on variations of surface radio refractivity and radio refractive index gradients in the Sub-Sahel.

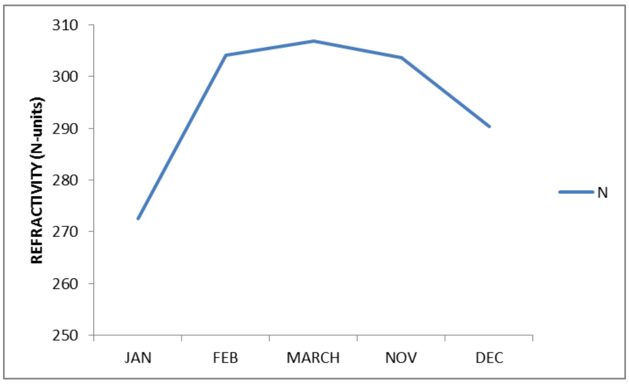

Figure 5: Dry season month's variation of refractivity at 1km for year 2015

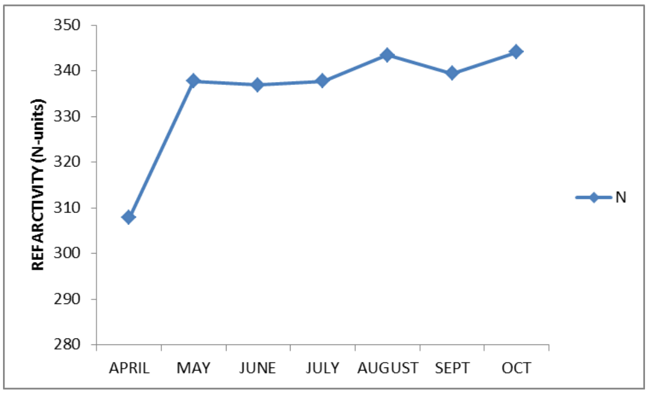

Figure 6: Wet season monthly variation of refractivity at 1km for year 2015

3.4 DRY AND WET SEASON VARIATION OF REFRACTIVITY GRADIENT AT THE HEIGHT OF 1KM

Figures 7 and 8 show dry and wet season variation of refractivity gradient at a height of 1km for the year 2015. The results show that refractivity gradient in the dry season month vary from -19.2 N-units/km in January to -22.1 N-units/km in December, while values vary from -26.7 N-units/km in April to -40.8 N-units/km in October for the wet season months. From the results obtained, it is observed that both dry and wet season months are Sub-refractive. An average value of refractivity gradient for the year 2015 at 1km is calculated to be -30.6 N-units/km. From the average value, it is observed that Abuja is generally under the sub-refractive condition which explains that radio wave are expected to move away from the earth`s surface and the line of sight range.

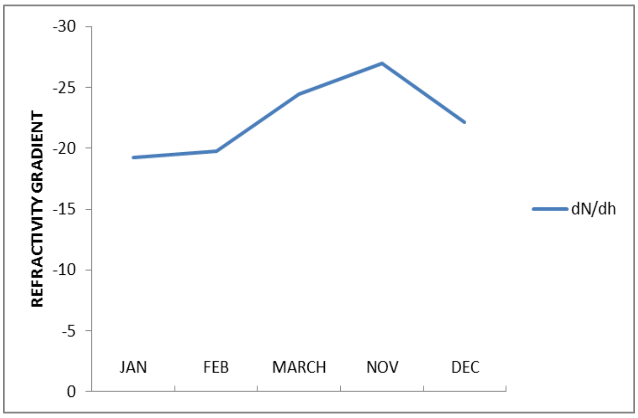

Figure 7: Dry season monthly variation of refractivity gradient at 1km for year 2015

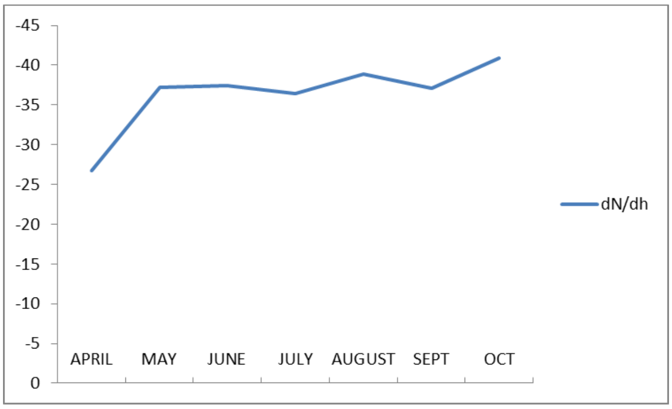

Figure 8: Wet season monthly variation of refractivity gradient at 1km for year 2015

3.5 VARIATION OF EFFECTIVE EARTH RADIUS FACTOR (K-FACTOR) FOR DRY AND WET MONTHS OF 2015

The variation of effective earth radius factor is shown in figures 9 and 10. Values of k-factor are observed to be lower in dry months than in the wet months. The values range from about 1.20 to 1.35 in the wet months and 1.13 to 1.20 in the dry months. The values are observed to be increasing slightly both in the dry and wet months. An average value of 1.25 is obtained for both the dry and wet season months combined. From the average value, it is observed that propagation of radio waves in Abuja in the year 2015 is characterized as sub-refractive.

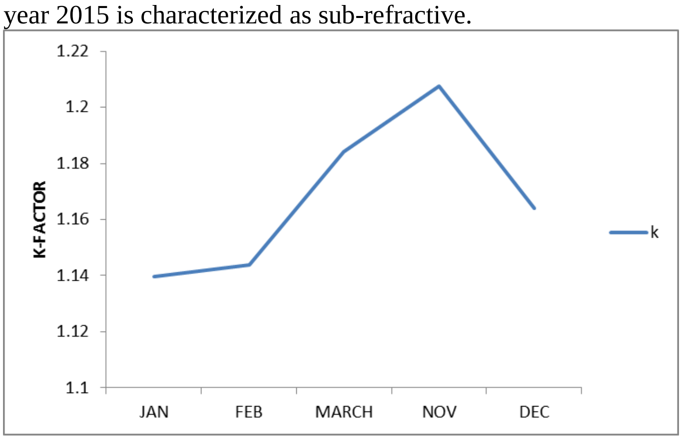

Figure 9: Variation of K-factor for the dry months of 2015

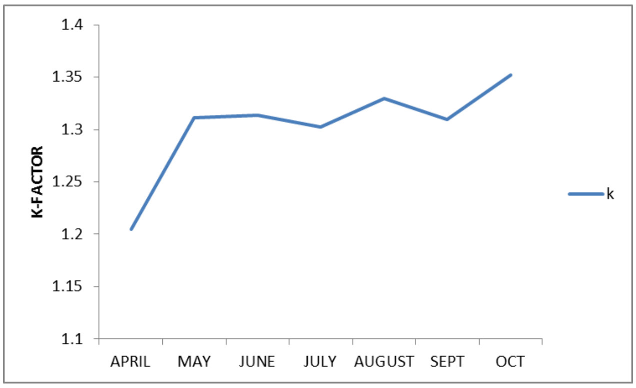

Figure 10: Variation of K-factor for the wet months of 2015

4 CONCLUSION

The radio refractive index and refractive index gradients variation in tropical environment has been investigated. It was observed from the results that, atmospheric parameters of temperature, pressure and relative humidity decreases with increasing altitude. Radio refractivity is observed to be decreasing with height, with raining season showing higher values than dry season. The average value of radio refractive index gradients and effective earth radius factor (k-factor) for 2015 were obtained as -30.6 N-units and 1.25 respectively. This implies that propagation over Abuja is sub-refractive. This explains that radio waves are expected to move away from the earth surface and the line of sight range.

ACKNOWLEDGEMENTS

The authors are grateful to the Nigerian Meteorological Agency (NIMET), Abuja for providing all the necessary data

REFERENCES

1. Adediji, A.T. and Ajewole, M.O. (2008). "Vertical Profile of Radio Refractivity gradient in Akure South-Western Nigeria", *Progress in Electromagnetic Research*, C4, 157-168
2. Agbo, G.A. and Okoro, O.N. and Amechi, A.O., (2013). "Atmospheric refractivity over Abuja,Nigeria". *International Research Journal of Pure and Applied Physics*. Vol.1, No. 1, pp.37-45
3. Akpootu, D.O and Iliyasu, M.I., (2017). "Estimation of tropospheric radio refractivity and its variation with Meteorological Parameters over Ikeja, Nigeria". *Journal of Geography, Environment and Earth Science International. ISSN: 2454-7352*
4. Chukwunike, O.C and Chinelo, I.U., (2016). "The Investigation Of The Vertical Surface Radio Refractivity Gradient In Awka, South Eastern Nigeria". *International Journal of Academic Research and Reflection*. Vol. 4, No. 6, 2016 *ISSN 2309-0405*
5. Hall, M. P. M., (1979). "Effects of the troposphere on radio communication".Peter Peregins Ltd, UK & US., P1-22
6. Igwe, K.C. and Adimula, I.A., (2009). "Variations of Surface Radio Refractivity and Radio Refractive Index Gradients In The Sub-Sahel". *Nigerian Journal of Space Research*. 135-144
7. ITU-R: (2004). *The Radio Refractive Index: Its Formula and Refractivity Data in: Recommendations* ITU-R P. 453–9 – 1970-1986-1990- 1992-1994-1995 19971999-2001, 2003.
8. Ukhurebor, K.E. Azi, S.O., Abiodun, I.C. and Ojiemudia, S.E., (2018). "Influence of Weather Variables on Atmospheric Refractivity over Auchi Town, Edo State, Nigeria".*Journal of applied science environmental management*. Vol. 22 (4) 471 – 475
9. Ukhurebor, KE and Azi, SO., (2018). "Review of Methodology to Obtain Parameters for Radio Wave Propagation at Low Altitudes from Meteorological Data: New Results for Auchi Area in Edo State, Nigeria". *J. King Saud University–Sci* (**doi:** https://doi.org/10.1016/j.jksus.2018.03.001