Assessment of Anomalous Propagation Conditions in Ondo City, South Western Nigeria for Microwave Applications

O. L. Ojo[*]   R. A. Adenodi

Department of Physics, Adeyemi College of Education, Ondo State, Nigeria

Abstract
Recent results of the in-situ measurement of radio climatological parameters of pressure, temperature and relative humidity carried out to investigate the trends in propagation conditions over altitude of 100-m in Ondo city Nigeria are presented. The assessments have been based on the time series of average value of the radio refractivity on the season of the year, characterization of radio refractivity gradient and the impact of secondary radio climatic data on terrestrial line of sight link design in Ondo city. We have used concurrent measurement of pressure, relative humidity and temperature for the period between 2017 and 2018. The results obtained confirmed the assertion that radio refractivity values are higher during the wet season months when compared with the dry season months. Yearly variation shows that the values of refractivity in the year 2018 are much higher than ones obtained in the year 2017. Results of radio refractivity gradient also shows a considerably large negative N value of about 288 N-units/km for the month of October and the value later becomes less negative in the remaining months of the year. Average value of k-factor during the dry and wet seasons for the year under study is about 1.37 and 1.47 respectively. This implies that, for microwave propagation in the Ondo environ, the propagation condition could be largely super-refractive during these seasons. A good relation also exists between Geoclimatic factor and season of the year. The overall will assist in achieving optimum performance of digital terrestrial point to point links in Ondo city.
Keywords: Propagation behavior, Time series analysis, Refractivity gradient, k-factor, Geoclimatic factor
DOI: 10.7176/JEES/9-4-07
Publication date: April 30th 2019

1. Introduction
For effective design of radio communication networks, it is paramount to assess the degree of atmospheric radio refractive index in the locality. The knowledge of refractive index is always needed when measurements are made in the air (Guo and Li, 2000). The path of a radio ray becomes curved when the radio wave propagates through the Earth atmosphere by reason of the variations in the atmospheric refractivity index along its trajectory (Bean and Dutton, 1968, Freeman, 2007). The impact of the bending of radio wave through the atmosphere becomes more pronounced as the digital microwave radio links continue to be applicable in the area of video, data and voice transmissions. Propagation paths of the electromagnetic waves are highly affected by the refractivity of the atmosphere, since the paths of propagation links are not a straight line (Gao *et al.,* 2008). To assess the extent of the degradation caused along the radiowave propagation paths by some meteorological parameters such as pressure, relative humidity and temperature, the study of radio refractive index is very important. The aforementioned meteorological parameters vary diurnally and seasonally especially in the tropical regions as pointed out in the work of Adeyemi and Emmanuel, (2011). Hence, quantitative knowledge of refractivity variations is very crucial to achieve good Quality of Signal (QoS) along the propagation links.

The subject of radio refractivity has received more attention especially in the temperate region regarding this subject matter. Among such studies are the works of Dhein et al., (1993); Řezáčová et al., (2003), Valma et al., (2010 and 2011) to mention but few. In recent times, the subject matter has started receiving attention in the tropics based on the work of Owolabi and Williams, (1970); Kolawole, (1980) and Falodun and Ajewole, (2006). The attention is much needed in the tropics due to the nature of its being an intense climatological environment. Hence, variability of atmospheric variables diurnally and seasonally will be more pronounced as noticed in the work of Adediji and Ajewole, (2008) and Igwe and Adimula, (2009) to mention but few. It was also noted that even small changes of these parameters leads to changes in the atmospheric refractive index (Priestly and Hill, 1985).

In this paper, we complement the earlier works that have been done by researchers in the tropics, especially Nigeria by using recent results from the in-situ measurement been carried out at Adeyemi College of Education, Ondo, Nigeria. The objectives of this paper are to analyze the dependence of the average value of radio refractivity, *N*, in different times of the day in Ondo, South-West, Nigeria on the seasons of the year. It also characterizes radio refractivity gradient and assess the impact of secondary radio climatic data on terrestrial line of sight link design in the city.

The rest of the paper is arranged as thus: section two provides information on the theoretical background, section three discusses the methodology adopted, results and discussion are presented in section four and conclusive remarks are provided in section five.

2. Theoretical Background

Radio refractivity, N is related to other meteorological parameters like atmospheric pressure, p (hPa), temperature, T (K) and partial water vapour pressure, e (hPa) by (ITU-R453-12, 2016) :

$$N = \frac{77.6P}{T} + 3 \times 10^5 \frac{e}{T^2} \tag{1}$$

e is also related to relative humidity, H (%) by:

$$e = \frac{He_s}{100} \tag{2}$$

where e_s is the saturated vapour pressure at the given air temperature t °C, and can be obtained from:

$$e_s = 6.112 \exp\left[\frac{17.502t}{(t + 20.97))}\right] \tag{3}$$

Equations (1)- (3) are valid for all the radio frequencies up to 100 GHz but with error less than 0.5% (ITU-R P. 453-12, 2016).

The radio refractivity gradient G (km^{-1}) at the surface can be obtained using:

$$\frac{dN}{dh} = -7.32 e 0.005577 N_s \tag{4}$$

where N_s is the refractive index at the surface. While, the radio refractivity gradient G (km^{-1}) in the upper air is also expressed as:

$$G = \frac{N_1 - N_2}{h_1 - h_2} \tag{5}$$

where N_1 and N_2 are radio refractivity values at heights h_1 and h_2 respectively. The effective earth radius factor k is then calculated by:

$$k = \left[1 + \left(\frac{dN}{dh}\right)/157\right]^{-1} \tag{6}$$

The effective earth radius factor k can also be used to classify the bending of rays of signals as sub-refractive, super-refractive and ducting respectively (Afullo *et al*., 1999, Freeman, 2007):

$$\text{Sub-refractive, if} \quad 1.33 > k > 0 \tag{7}$$
$$\text{Super-refractive, if} \quad \infty > k > 1.33 \tag{8}$$
$$\text{Ducting, if} \quad -\infty < k < 0 \tag{9}$$

Furthermore, the prediction of radio field strengths at a location is easily facilitated with this approach.

Geoclimatic factor (K) can be determined based on ITU-R P.530-17, (2017) using the point refractivity gradient in the lowest 50 m of the atmosphere not exceeded for 1% of an average year as:

$$K = 10^{-(4.2 - 0.0029 dN_1)} \tag{10}$$

where dN_1 is the point refractivity gradient in the lowest 50 m of the atmosphere not exceeded for 1% of an average year.

3. Methodology

Ondo City (7.09°N 4.79°E) is the second largest city in Ondo State, Nigeria. The city accommodates different

higher institutions among are Ondo State University of Medical Sciences established in 2015. Wesley University of Science and Technology is a private university owned by the Methodist Church of Nigeria and Adeyemi College of Education, a federal government higher education institution. The city belongs to the tropical wet part of Ondo State where there is an excess of moisture. The average relative humidity is about 66% in dry season months while in the wet season months it is as high as 84–91%. Ondo town climate is also characterized by large temperature fluctuations. Difference between the maximum temperature and minimum temperature in the dry season months is about 13.2℃, while an average temperature during the wet season months is about 26℃ (Worldwide weather online, 2018). Due to the commercial and educational activities in this city, there is a high demand of good QoS for customer's satisfaction, hence the need for this research.

The experimental site for this work is the School of Sciences building, Adeyemi college of Education Ondo of Ondo State, Nigeria. The weather station used for the in-situ measurement is the Davis 6162 Wireless Pro2 equipped with the Integrated Sensor Suite (ISS). The fixed measuring method by a high tower was employed for the measurement with one sensor each placed at the ground level for surface measurement and the others at the altitudes 50 m and 100 m on the tower for continuous measurement.

Two years of data spanning 2017-2018 are used in this work. The measured values of pressure, temperature and humidity at the surface as well as at heights 50 m and 100 m were analyzed for the observed readings at 0.00 hrs, 06.00 hrs, 12.00 hrs and 18.00 hrs, local time. Further analyses were carried out by averaging each hour to give twenty four hour data for the diurnal variation over each month as well as for the seasonal variation.

4. Results and Discussion

Based on equations (1) to (3), refractivity N have been determined, while refractivity gradients were obtained using equations (4) and (5). The values of k-factors and Geoclimatic factor, K were also obtained using equations (6) and (7) respectively. Figure 1 presents the dependence of the average value of radio refractivity, N for the period under study on the seasons of the years (2017-2018). The numbers of the months are marked starting from 1 up to 24 representing January 2017 to December 2018. The data presented in Figure 1 show that the maximum values of radio refractivity N averaged over the month were recorded at the surface level and the minimum N values were at 100 m heights during all the years from the period analyzed. The maximum N value of 374 N-units during the period of analysis was recorded in May 2018 at the surface level, while the minimum N value of 326 N-units was recorded in January 2018 at 100 m height. In general, the result truly shows seasonal variation over the study area as earlier reported by some researchers in Nigeria (Falodun and Ajewole (2006), Adediji and Ajewole 2008), Ojo *et al* (2017) to mention but few. Figure 2 further presents the monthly average of N at the two selected heights over the analyzed years. As depicted in Figure 2, the average maximum N value of 375-N units occurred in the month of October that corresponds to the end of rainy season, while the average minimum N value of 333-N units occurred in the month of January, which corresponds to the peak of dry season months. The two plots actually revealed high level of seasonal trends of radio refractivity.
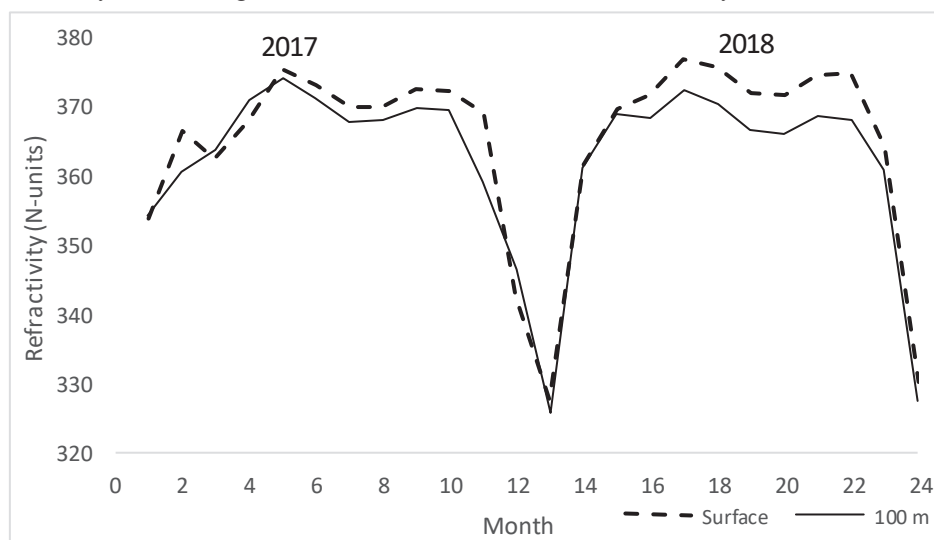

Figure 1: Dependence of the average value of radio refractivity, N for the period under study on the seasons of the years (2017-2018).
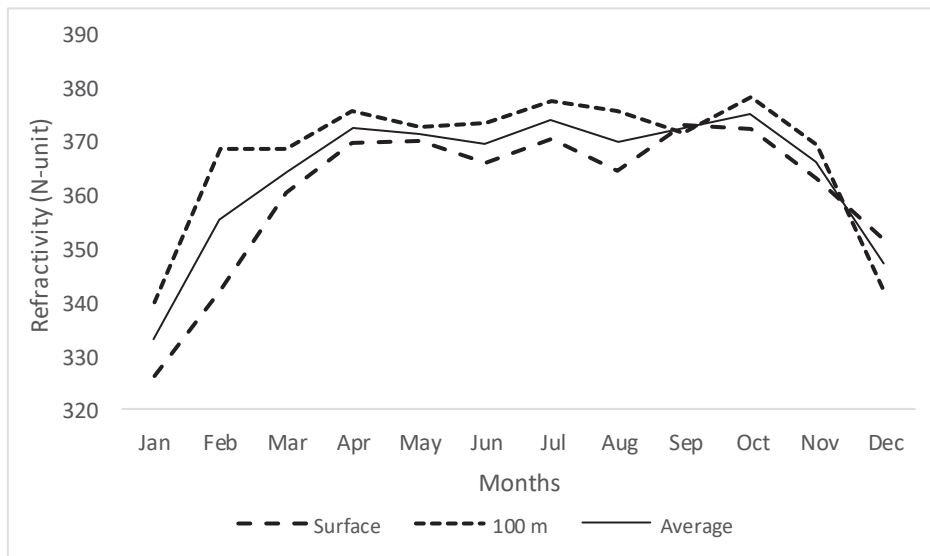
Figure 2: Average radio refractivity at the surface and 100 m heights.

A typical plot of the dependence of *N* values at the surface level based on the time of day is also presented in Figure 3. The result shows that irrespective of the hours of the day, *N* values attained its minimum values in February with the least *N* value of 309 N-units occurring at 12 Noon. Next to February is the month of January with *N* minimum value of 352 N-units occurring at the same hours of the day. The maximum *N* value of 377 N-units also occurred in the month January at 6 hrs of the day, followed by *N* value of 372 N-units in the month October at 18 hrs of the day. The overall results also indicated variation in the N values at different hours of the day. This is as a result of variations in the atmospheric parameters with changes in temperature, relative humidity and water vapor in the atmosphere.
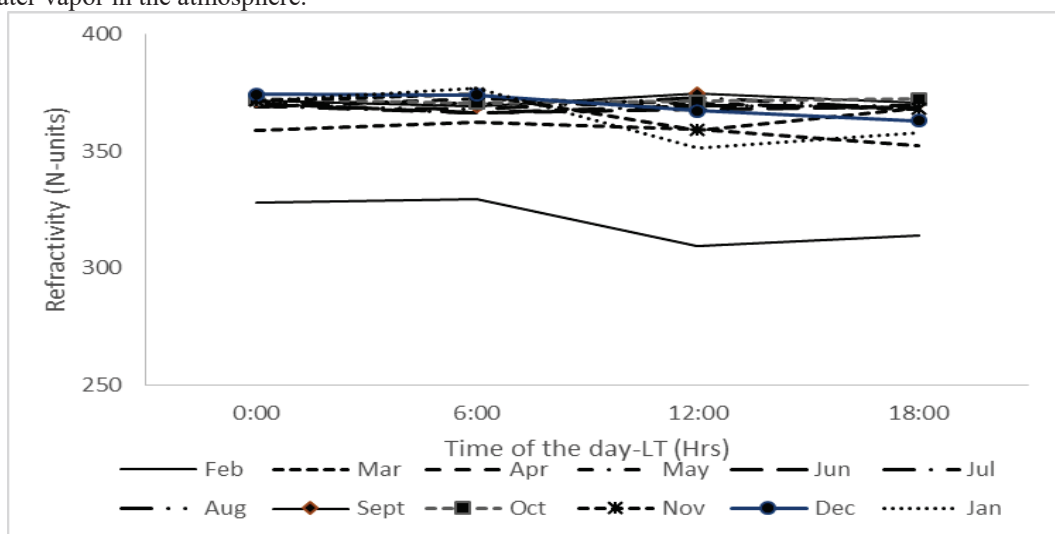

Figure 3: The dependence of the average value of radio refractivity, N for different time windows of the day, on the seasons of the years (2018-2019).

Figure 4 presents average monthly variation of radio refractivity gradient for the period under study. The result shows a considerably large negative *N* value of about 288 N-units/km for the month of October could be observed. The month represents the end of rainy months. The value later becomes less negative in the remaining months of the year. The lowest negative point refractivity gradient of about -6.9 N-units/km occurred in the month of February. This result is in agreement with what was observed by Ojo *et al.,* 2017. In the report, it was observed in some specific locations in Nigeria that the refractivity gradient also becomes less negative at some specific refractivity gradient values.

| Station	Layers	Resistivity values (Ωm)	Thickness (m)	Depth (m)	Curve Types	Reflection Coefficient	Probable Lithology
VES 1	1	448	1.1	1.1	H	0.95	Top soil
	2	364	12.2	13.3			Weathered basement
	3	14244	-	-			Fresh basement
VES 2	1	183	1.0	1.0	AA	0.36	Top soil
	2	370	15.8	16.8			Clayey sand
	3	424	13.1	29.9			Weathered basement
	4	891	-	-			Fractured basement
VES 3	1	369	0.7	0.7	HKH	0.53	Top soil
	2	224	1.4	2.2			Clayey sand
	3	378	3.0	5.2			Lateritic clay
	4	349	1.9	7.1			Weathered basement
	5	1151	-	-			Fractured basement
VES 4	1	358	1.6	1.6	H	0.97	Top soil
	2	323	8.7	10.3			Weathered basement
	3	24744	-	-			Fresh basement
VES 5	1	182	0.8	0.8	KH	0.89	Top soil
	2	347	15.0	15.8			Lateritic clay
	3	288	3.5	19.3			Weathered basement
	4	5045	-	-			Partially fractured basement
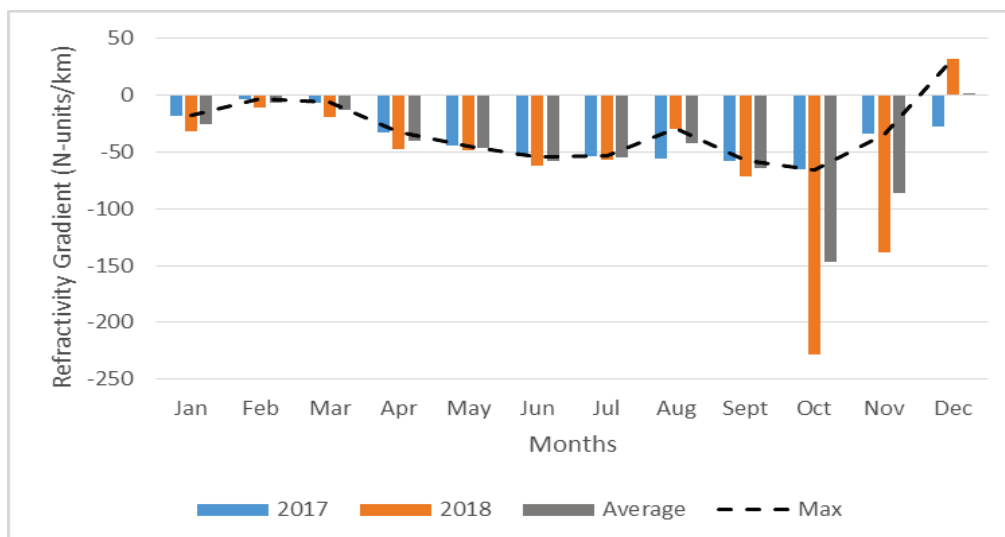
Figure 4: Average monthly variation of radio refractivity gradient for the period under study.

Figure 5 also presents monthly variation of Geoclimatic factor *K* for multipath fading prediction in the study locations and mean values of *k*-factor during period under study. It could be seen that *k*-factor values shows seasonal type dependence. For example, during the dry season months (Nov-Dec and Jan-March) the mean k-factor value in Ondo city range between 0.76 to 2.04 with maximum value in the month of March and minimum in the month of December. The average value of k-factor during the dry season months for the year under study is about 1.37. This implies that, for microwave propagation in the Ondo environ, the propagation condition could be largely super-refractive during this season. The mean values of the k-factor over the study locations during the wet season months also shows that k-factor is generally higher in the rainy season months than in the dry season months. This result is in agreement with the observation by Ojo *et al.,* 2017. The results closely follows the results observed in Akure. The average value of k-factor during the wet season months is about 1.47. This implies that, for microwave propagation in Ondo city, the propagation condition could also be largely super-refractive. Comparison of k-factor with the predicted value by the International telecommunication Union Recommendations (ITU-R) shows that k-factor values at the study locations are higher than the prescribed value of 1.33 (ITU-R P.453-12, 2016). The main application of the Geoclimatic factor is in the area of fade depth needed in the radio link design for good QoS in Ondo city. It could be seen that distinct relationship exists between the Geoclimatic factors (*K*) and the season of the year. For example, averaged minimum mean value of Geoclimatic factor of about 8.02×10^{-5} for the month of May whereas the observed averaged maximum value of

Geoclimatic factor K was 7.21×10^4 in the month of October. These results is similar to one reported for Akure in the work of Ojo *et al*., 2017. The implication is that similar value of Geoclimatic factor observed in Akure can be used for Ondo city to cater for adequate fade margin necessary for a reliable radio link performance in the city.
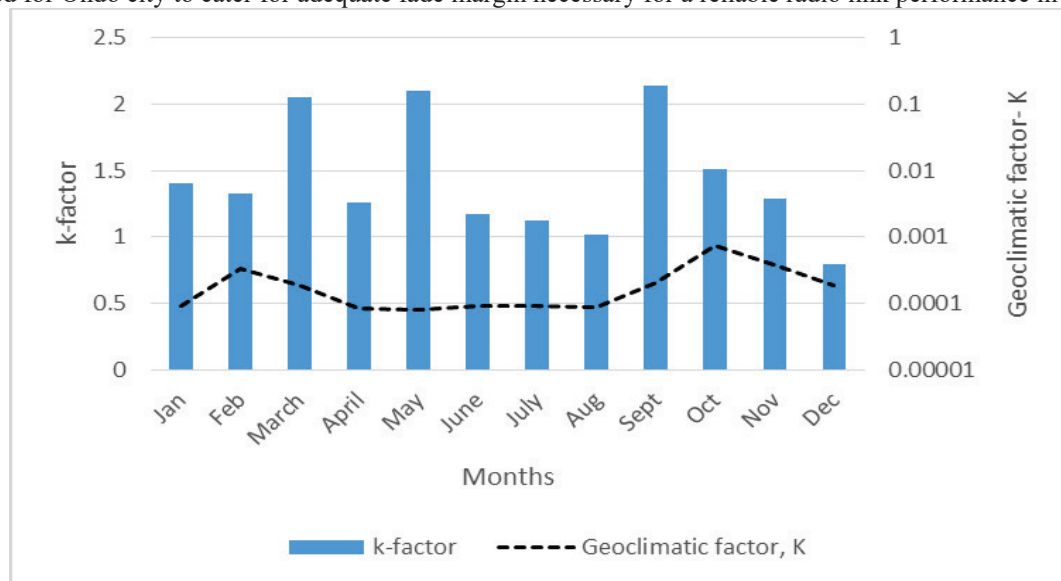

Figure 5: Average monthly variation of Geoclimatic and *k*-factor for the period under study

5. Conclusion

Recent results of the investigation of microwave anomalous propagation conditions in the first 100-m height in Ondo city, Southwestern, Nigeria has been presented. It could be observed that both yearly and monthly average radio refractivity actually revealed high level of seasonal trends. The *N*-values also shows variation at different hours of the day. Results of radio refractivity gradient shows a considerably large negative *N* value of about 288 N-units/km for the month of October and the value later becomes less negative in the remaining months of the year. Average value of k-factor during the dry and wet season for the year under study is about 1.37 and 1.47 respectively. This implies that, for microwave propagation in the Ondo environ, the propagation condition could be largely super-refractive during these seasons. Comparison of the k-factor with the predicted value by the ITU-R shows that k-factor values at Ondo city is higher than the recommended value of 1.33 by the ITU. Geoclimatic factor needed for fade depth estimation in the radio link design for good QoS in Ondo city shows distinct relationship with the season of the year. The overall result will be useful in planning terrestrial propagation links with good QoS in Ondo city.

Acknowledgement

References
Adediji A.T and Ajewole M.O (2008): Vertical profile of radio refractivity gradient in Akure, south-West, Nigeria. *Progress in Electromagnetic research C, vol. 4, 157-168.*

Adeyemi B and Emmanuel I (2011): Monitoring tropospheric radio refractivity over Nigeria using CN-SAF data derived from NOAA-15, 16 and 18 satellite, *Indian Journal of Radio and Space Physics*, Vol. 40, pp 301-310.

Afullo, T. J, Motsoela, T and Molotsi, D.F (1999): Refractivity Gradient and k-factor in Botswana. Radio Africa. 107-110

Ayantunji B.G Okeke P.N and Urama J.O (2011): Diurnal and seasonal variation of surface refractivity over Nigeria, *Progress in electromagnetic research B, Vol. 30, 201-222.*

Bean B.R.and Dutton E.J., Radio Meteorology, Dover Publications, New York 1968.

Dhein, N.R, Pontes, M.S and Silva M.L (1993): Statistical behavior of refractivity gradient in the tropics, *IEE conference Publ, No. 370, 340-343, London.*

Falodun S.E and Ajewole M.O (2006): Radio refractivity index in the lowest 100 m layer of the tropospheric in Akure, South-western*, J. of Atm and Solar-terrestrial Physics, Vol. 68, 236-243.*

Freeman, R.L. Radio System Design for Telecommunications, 3rd ed., Wiley–Interscience, New York 2007.

Gao J, Brewster K and Xue, M (2008): Variation of radio refractivity with respect to moisture and temperature and influence on radar ray path, *Advances in Atmospheric science, Vol. 25 (6), 1098-1106.*

Guo G., S. Li, (2000**):** Study on the Vertical Profile of Refractive Index in the Troposphere, *Int. J. Infrared Millimeter Waves* 21, 1103-1111

Igwe K. C and Adimula (2009): Variation of surface radio refractivity and radio refractive index gradients in the sub-Sahel, *Nig. J. of space research, Vol. 6, 135-144*

ITU-R, 453-12: The radio refractivity index; its formula and refractivity data, 2016.

ITU-R P.530-17: Propagation data and prediction methods required for the design of terrestrial line-of-sight systems, 2017.

Kolawole L.B (1980): Vertical profiles of radio refractivity over Nigeria, *J. of West African Association*, Vol. 26, 41-60.

Ojo O. L, Ojo J. S and Pelumi Akinyemi (2017): Characterization of secondary radioclimatic variables for microwave and millimeter wave link design in Nigeria. *Indian Journal of Radio & Space Physics,* Vol. 46, September 2017, pp. 83-90

Owolabi, I.E and Williams V.A (1970): Surface radio refractivity patterns in Nigeria and the southern Cameroons, *J. West Afri. Sc, Vol. 15 (1), 3-17*

Priestly J.T and Hill R.J (1985): Measuring high frequency refractive index in the surface layer, *Journal of Atmospheric and Oceanic technology, Vol 2, 233-251.*

ŘEZÁČOVÁ Daniela, Ondřej FIŠER and Lucas RAMÓN SÁEZ (2003), Statistics of Radio Refractivity Derived from Prague Radio sounding Data, *RADIO ENGINEERING*, VOL.12, NO. 4, 84-86

Valma Z, Tamosiunaite M, Tamosiunas S, Tamosiuniene M and Zilinskas M (2011): Variation of radio refractivity with height above ground, *Electronics and Electrical Engineering, Telecommunication Engineering ISSN 1392-1215, No 5, 23-26.*