NIGERIA JOURNAL OF PURE AND APPLIED PHYSICS

Nigeria Journal of Pure and Applied Physics, Vol. 7, No. 1, pages 19–25, 2017

REDUCED-TO-SEA-LEVEL VALUE OF MICROWAVE RADIO REFRACTIVITY OVER THREE STATIONS IN NIGERIA

A. T. Adediji†

Department of Physics, The Federal University of Technology, Akure, Nigeria

†Corresponding Author's Email: kadediji@futa.edu.ng , kunleadediji2002@yahoo.co.uk

Abstract: Adequate knowledge of the temporal and spatial variations of surface refractivity, N_s is required for planning of broadcasting services including terrestrial radio links over a region. The reduced–to–sea–level refractivity, N_0 values removes the elevation–dependence of surface refractivity in a bit to enhance comparison and contouring of values for different meteorological stations. In this study, in–situ measurement of atmospheric pressure, temperature and relative humidity using Wireless Weather Stations (Integrated Sensor Suit, ISS) was carried out over three different meteorological stations in Nigeria, namely: Akure (7.15^{0}N, 5.12^{0}E) South – Western Nigeria, Minna (9.61^{0}N, 6.55^{0}E) North – Central Nigeria and Nsukka (6.85^{0}N, 7.39^{0}E) South – Eastern Nigeria. Two years of measurement (January, 2008 to December, 2009) were used to compute the surface radio refractivity and its reduced – to – sea – level value. The results show that surface refractivity has seasonal tendency and is highest in the wet season and low in the dry season months. The surface refractivity values and the climatic tendency for reduced–to–sea–level refractivity were highest in Nsukka compared to the other two stations (Akure and Minna). The implication of the results is that the correlation of VHF/UHF field strengths with diurnal and seasonal variations of N_s partly explains the low signal reception in some locations especially from long distance transmitting stations when N_s is minimum. It further shows that the worst case propagation parameters are used for design purposes.

Keywords: microwave, surface refractivity, reduced-to-sea-level, troposphere, scale height

1. INTRODUCTION

Refractivity is the physical property of a medium as determined by its index of refraction and it is responsible for various phenomena in radio wave propagation such as ducting and scintillation, refraction and fading, range and elevation errors in radar acquisition [1].

The way by which radio signals travel from the transmitter to receiver is of great importance when planning a radio communications network. This is governed to a certain extent, by the conditions of the atmosphere through which the waves traverse. Thus, the study and use of atmospheric parameters with regard to radio communication require the knowledge of radio refractivity to characterize the atmosphere for terrestrial and earth – satellite communication purposes [2].

There are two main layers that are of interest from a radio communications perspective. The first is the troposphere (lower atmosphere) which extends from the earth surface to an altitude of about 10 km at the earth poles and 17 km at the equator and tends to affect radio frequencies above 30 MHz [3]. The second is the ionosphere which is a region that extends from around 60 km up to 700 km producing ions and free electrons which affect radio signals at certain frequencies; typically those below 30 MHz

Profiles of refractivity gradient within 1 km of the atmosphere are important for the estimation of some propagation parameters, such as super-refraction and ducting phenomena, and their effects on radar observations and Very High Frequencies (VHF) field strength at points beyond the horizon [4 - 5]. Knowledge of the refractivity is thus essential in order to design reliable and efficient radio communication (terrestrial and satellite) systems. Similarly, to estimate the performance of terrestrial radio links, the refractive index of the troposphere is equally a very important parameter to be considered.

Planning of broadcasting services above 30 MHz has been on Recommendation 370 of the 'International Telecommunication Union (ITU-R)' [6 - 7]. However, available data are from measurements performed in Europe, North America and Japan with little inputs from the tropical region, particularly Africa. The ITU in response to these observed lapses initiated a radio-wave propagation measurement campaign in Africa in 1984 with two experiments performed in Burkina Faso between 1986 and 1989 with a number of experiments further conducted in some locations in Africa [6]. However, none of these studies were carried out in Nigeria; and for optimized planning of radio services, data which take into account the specific climatic condition is required [8]. It therefore becomes important to bridge the knowledge gap for proper understanding of the propagation mechanisms associated with the country. Hence, this work present the result of two years of measurement of radio meteorological parameters (temperature, humidity and pressure) of the troposphere **for** three locations in Nigeria. The measured data were used to compute surface radio refractivity and its reduced–to–sea–level values. The diurnal, seasonal and annual variations over the locations were also deduced.

2. SURFACE REFRACTIVITY, N_s AND REDUCED-TO-SEA-LEVEL REFRACTIVITY, N_0

The lower atmosphere (troposphere) is not homogenous [9]. This situation affects the electromagnetic wave propagation in it. Worse propagation conditions lead to decreased power levels at transmitter/receiver and to increased fading on communication links [10]. The refractive index of the air in the troposphere plays a dominant role in radio signal propagation and the radio communication applications that employ tropospheric radiowave propagation.

The refractive index in the troposphere falls slowly with height and the resulting refraction causes the radio horizon to appear to be 1.33 times further away than the geometric horizon [11]. Changes in the value of the tropospheric radio refractive index can curve the path of the propagating radio wave [12]. It thus follows that the radio link systems must be planned and designed in such a way that its optimal performance would be achieved and one way to achieve this is to estimate the atmospheric refractive index [9].

When light waves travel through a medium of material composition, part of its energy is lost to the medium in a process termed refraction [13]. Hence, microwave signal propagation in the troposphere suffers refraction; a consequence of the atmospheric constituents which include temperature, pressure, humidity, water vapour and other green-house gases. Radio refractivity N is thus a measure of deviation of refractive index, n of air from unity scaled – up in parts per million and given by [14]:

$$n = 1 + N \times 10^{-6} \tag{1}$$

where n is refractive index and N is a dimensionless quantity expressed in N−units.

In terms of measured meteorological quantities, the refractivity N can be expressed as [14 - 16]:

$$N = N_{dry} + N_{wet} = 77.6\ \frac{P}{T} + \ 3.73\ \times\ 10^5\ \frac{e}{T^2} \tag{2}$$

with the dry term, N_{dry}, given by:

$$N_{dry} = 77.6\frac{P}{T} \tag{3}$$

and the wet term, N_{wet}, by:

$$N_{wet} = 3.732 \times 10^5\, \frac{e}{T^2} \tag{4}$$

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

The dry term contributes about 70% to the value of N and wet term is responsible for major part of variation in N at a given location in the atmosphere. Equation (2) can be used for radio frequencies up to 100 GHz. The error associated with the use of this expression is less than 0.5% [14].

The relationship between water vapour pressure, e and relative humidity is given by:

$$e = \frac{H.e_s}{100} \tag{5}$$

with:

$$e_s = EF.a.exp\left[\frac{\left(b-\frac{t}{d}\right).t}{t+c}\right] \tag{6}$$

and:

$$EF_{water} = 1 + 10^{-4}[7.2 + P.(0.00320 + 5.9.10^{-7}.t^2)] \tag{7a}$$

$$EF_{ice} = 1 + 10^{-4}[2.2 + P.(0.00382 + 6.4.10^{-7}.t^2)] \tag{7b}$$

where t is temperature (^{0}C), P is pressure (hPa), H is relative humidity (%) and e_s is saturation vapour pressure (hPa) at the temperature t(^{0}C) and the coefficients a, b, c and d are for water: a = 6.1121, b = 18.676, c = 257.14 and d = 234.5 (valid between -40^0 to +50^0) and for ice a = 6.1115, b = 23.036, c = 279.82 and d = 333.7 (valid between -80^0 to 0^0). **[**14]

The surface radio refractivity, N_s is the refractivity determined at ground level of the study location. Its value is sensitive to changes in (i.e. a function of) temperature, pressure and humidity [17] and therefore decrease on the average with elevation. Elevation angle errors and range errors can also be predicted from N_s value [18].

Surface radio refractivity is also known to have high correlation with radio field strength values [19, 3]. Thus, a good knowledge of N_s as well as its diurnal and seasonal variability is particularly useful in planning terrestrial radio links [20].

The reduced – to – sea – level value, N_o of surface refractivity was introduced to remove the dependence of surface refractivity on site elevation/altitude in order to provide more accurate description of the refractive variations [21].

Assuming the reference atmosphere and height of the site (or station elevation) above sea level to be h in km, with a scale height H in km, N_0 can be computed from:

$$N_0 = \ N_s \exp(\ h/H) \tag{8}$$

where H has a numerical value of 7.0 km in the tropics [22 - 23].

The importance of N_0 lies in the fact that most of the variability in N_s disappears if the reduced – to – sea – level is employed in the analysis of surface refractivity [7].

The scale height, H is defined as the height at which the upward decrease of the refractivity reaches $e^{-1}$of the surface value, N_s. It is an important radio meteorological parameter used in the determination of refractivity reduced to sea level value which gives the station refractivity values four to five times more accurate than the surface refractivity values [24]. The scale height is associated with the vertical distribution of atmospheric gases and can also be empirically derived from available vertical profiles of N. Higher values of H (approximately 8 km) are associated with dry atmosphere while lower values (approximately 6.5 km) are associated with saturated atmosphere. H = 7.0 km is accepted as a compromise value for different atmospheric conditions [22]. However, more appropriate H-values derived from prevailing local conditions are generally preferable.

2. RESEARCH SITES, DATA ACQUISITION TECHNIQUE AND COMPUTATION OF RESULTS

This study considered three (3) stations in Nigeria (Fig. 1) namely: Akure in the South – Western part of Nigeria, Minna in the North – Central of Nigeria and Nsukka in the South – Eastern Nigeria. The Akure site is located at the old Nigerian Television Authority (NTA) transmission station at Iju in Akure North local government area of Ondo State, Nigeria. The Minna site is located in the premises of NTA Minna, Niger State in the North – Central of Nigeria while the station at Nsukka is located at the Centre for Basic Space Science (CBSS) in the premises of the University of Nigeria, Nsukka in Enugu State, South Eastern Nigeria. Table 1 shows the coordinates, altitudes and the climatic conditions of the three stations.

The meteorological parameters (temperature, pressure and relative humidity) were measured using the Davis 6162 Wireless Vantage Pro2 equipped with the Integrated Sensor Suite (ISS), a solar panel (with an alternative battery source) and the wireless console. The ISS (Fig. 2) is a versatile wireless weather station that combines the sensors for pressure, temperature, relative humidity, UV index and dose, solar radiation, anemometer, the sensor interface module (SIM), among others.

The sensor suite is housed inside a radiation shield, protecting the sensors against direct solar heating and additional sources of reflected and/or radiated heat. The SIM attached to the ISS transmits measured values of the weather variables to the data logger which is connected to the sensor via a wireless radio connection to ensure a continuous recording of the measured atmospheric parameters on a 24-hour basis. The logged – in data are then downloaded to a dedicated computer. The error margin of the ISS device for temperature, pressure and

Table 1: Geographic coordinates, altitudes and climate of the research sites.

Research Site	Latitude	Longitude	Altitude (m)	Climatic Region
Akure	7.15^0N	5.12^0E	358	Tropical Rainforest
Minna	9.61^0N	6.55^0E	381	Tropical Savannah
Nsukka	6.85^0N	7.39^0E	306	Mangrove Rainforest

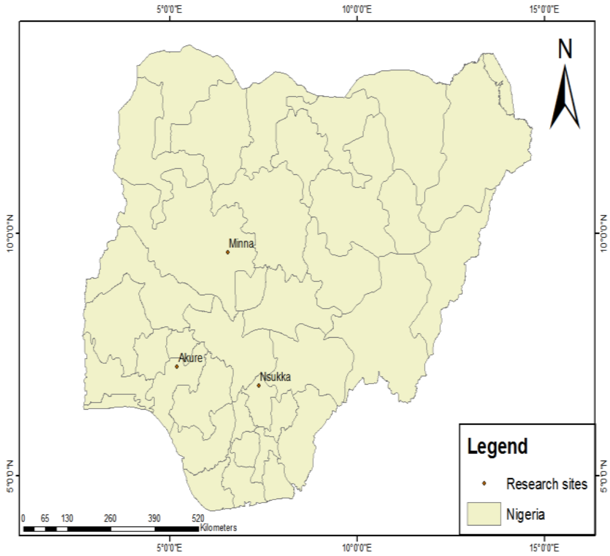

Fig. 1: Digitized map of Nigeria showing the research sites

Fig. 2: The Integrated Sensor Suite (ISS) on the ground surface at a typical research site.

relative humidity are $\pm 0.1^0$C, ± 0.5 hPa, and ± 2% respectively.

The ISS has a measuring range of 0 – 100% relative humidity and -30 to 70^0C temperature. The power requirement is 5 – 15V DC, 2mA. The Barometric Pressure Sensor is in a weatherproof housing and has a measuring range of 600 – 1, 060 hPa, and power requirement of 10 – 30V DC, 4mA. More details about the instrumentation set up is available in [25]. The data of temperature, pressure and relative humidity obtained from the ISS was used to compute surface refractivity from which the reduced – to – sea – level value was determined over all the three stations considered for this study.

Indirect method (fixed measurement by high tower) of measurement was used. The method provides an accurate measurement of the parameters required for the estimation of refractive index at a fixed height.

Two years of data spanning January 2008 to December 2009 are employed in the study. The data were collected on the ground level (about 5 m above the earth's surface) at which the ISS was placed to measure the surface atmospheric parameters. The measurement covers 24 hours each day beginning from 00 hours local time (LT) to 23:00 hours and for a time interval of 30 minutes.

The measured values of relative humidity, H (%) and temperature, t (^{0}C) were used to calculate the water vapour pressure e, at the ground surface using equation (5) where the saturated vapour pressure was calculated from equation (6) by employing equation (7a) using the values of temperature in degree Celsius and pressure P, in hPa.
Averages of the daily variation of meteorological parameters for each month were deduced from the data collected, and the results used to compute the surface radio refractivity using equation (2). Using the height above sea level of the surface at each of the three stations and the calculated surface refractivity, the reduced – to – sea – level value refractivity was then calculated from equation (8).

4. RESULTS AND DISCUSSION

4.1 Diurnal variation of Reduced-to-sea-level refractivity at the three stations for years 2008 - 2009

Figures 3 - 6 show typical variation of N_o during the intense dry period (January), the period of commencement of rain (March), period of intense rain (July) and period of commencement of the dry/harmattan (November). During the dry season (Fig. 3), the diurnal variations of N_o display a sharp and steady fall from around 09:00 – 15:00 h local time (LT), and a sharp rise from around 16:00 – 23:00 h LT daily. Minimum values of N_o were observed between 10:00 – 14:00 h LT for Minna and Akure, and 21:00 – 22:00 h LT for Nsukka. The low values of N_o observed during this period is due to very low values of water vapour pressure, and high temperature values associated with this period of the day during the dry season in this part of the globe.

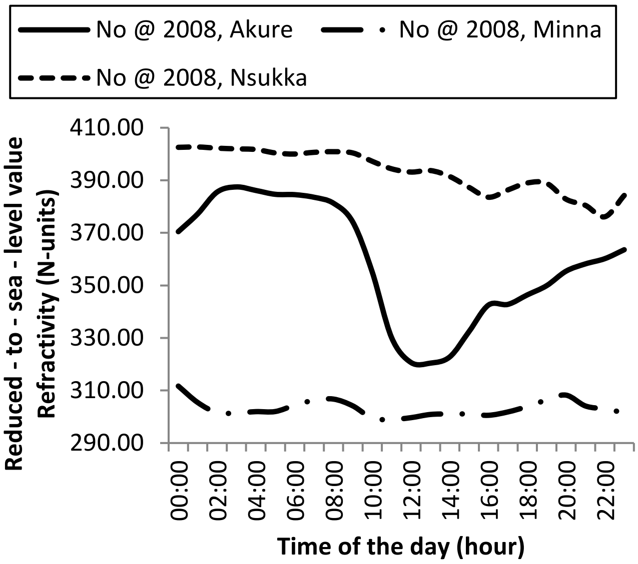

Fig. 3: Diurnal variation of reduced-to-sea-level refractivity for a typical day in the month of January 2008 across the three stations.

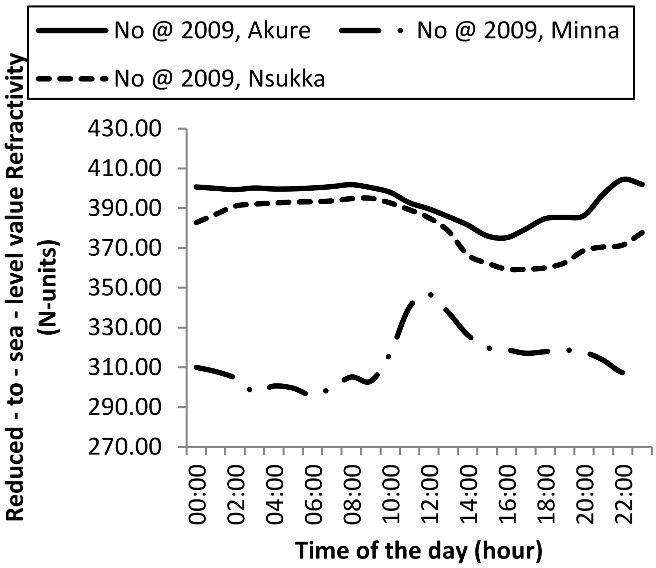

Fig. 4: Diurnal variation of reduced-to-sea-level refractivity for a typical day in the month of March 2009 across the three stations.

During the period of the commencement of the rainy season, typically in March 2009 (Fig. 4), the diurnal variations of N_o revealed that steady drops were observed from around 02:00 – 07:00h LT in Akure and Minna, and 13:00 – 18:00h LT across the three stations. A sharp rise was observed from around 11:00 to 13:00h LT for Minna, and also from around 21:00 – 22:00h LT for Nsukka. The values was fairly steady for the evening periods across the three stations.

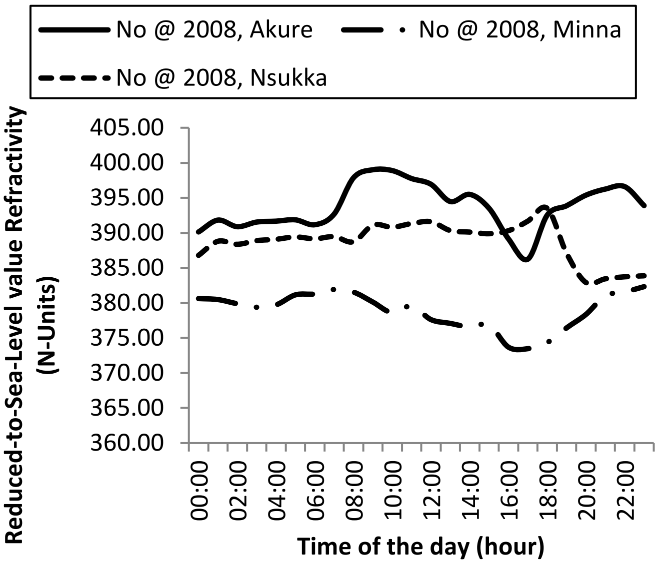

Fig. 5: Diurnal variation of reduced-to-sea-level refractivity for a typical day in the month of July 2008 across the three stations.

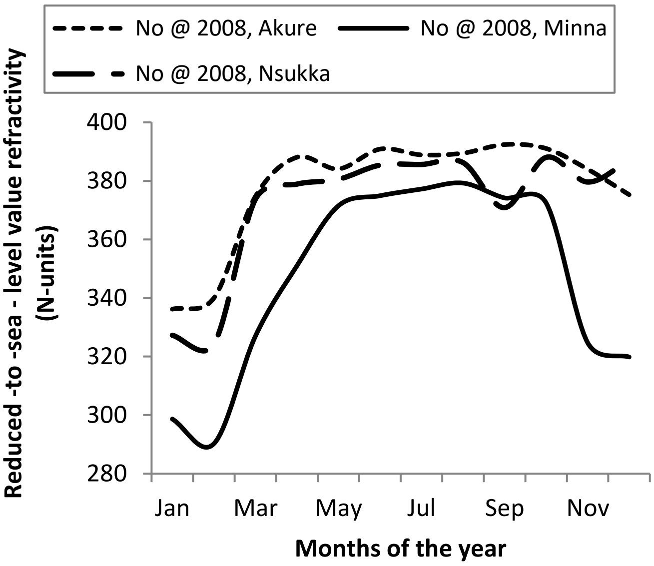

Fig. 7: Seasona; variation of reduced-to-sea-level refractivity across the three stations for year 2008

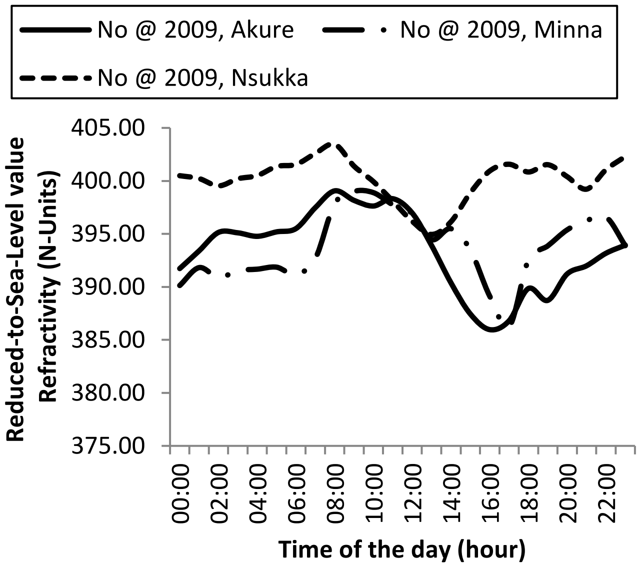

Fig. 6: Diurnal variation of reduced-to-sea-level refractivity for a typical day in the month of November 2009 across the three stations.

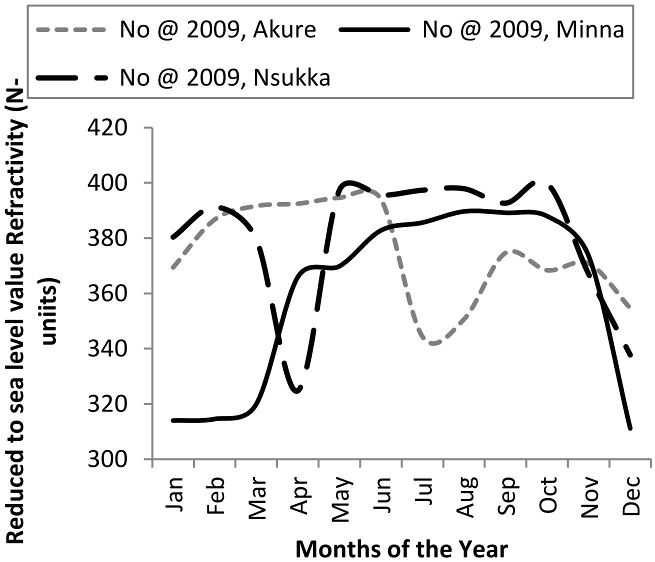

Fig. 8: Seasonal variation of reduced-to-sea-level refractivity across the three stations for year 2009

In figure 5 the diurnal variation of N_o values during the period of intense rain (July) presents irregular oscillations starting from around 07:00h – 18:00h LT across the stations. The values were also observed to be generally high mainly due to the presence of high humidity (about 100%) thereby resulting in high water vapour pressure in the atmosphere.

Figure 6 shows the typical diurnal variation of N_o during the commencement of the dry/harmattan period (November) where an irregular oscillation was observed. Sharp rise in N_o values was observed from around 07:00h – 08:00h LT across the stations with a corresponding sharp and steady fall from around 19:00h – 14:00h LT at Nsukka, 12:00h – 18:00h LT at Akure and 14:00h – 18:00h at Minna. High values of N_o observed during this period could be due to the convective activity of the atmosphere, that is, lifting of the boundary layer with significant amount of water vapour present in the atmosphere owing to large rainfall activities in the months preceding the commencement of the harmattan period [26]**.** It is expected that by December, the observed N_o values would drop as the harmattan haze begins to take effect which further culminate into low values around January where the dry season would be intense.

4.2 Seasonal Variation of Reduced – to – Sea – Level Value Refractivity in the Three Stations from 2008 – 2009

Figures 7 and 8 show the seasonal variation of reduced – to – sea – level value refractivity over the three stations for the two years period under study. For Akure station, N_o values for 2008 started from a low value of 336 N-units in January and rose steadily through February from 340 N-units to a peak value of 392 N-units in September, before it dropped steadily in October to the minimum in December. The month of December **is** when the dry harmattan commenced at this location. The drop continued way into January 2009 at 369 N-units before **it** began to rise again in February at 386 N-units to an all time high of 394 N-units in May and June which is the period of intense rain for the zone. The sharp fall in July can be attributed to abnormal cessation of rain during this period in this location which is expected to be period of intense rain. This abnormal cessation of rain in July can be attributed to the consequence of climate change being experienced all the world. Rainfall activity was observed for some few days in November before the harmattan period commenced later in the month and continued into December with a N_o value of 354 N – units.

For Minna station, N_o values dropped from 298 N-units in January to 290 N-units in February indicating a prolonged dry season. The humidity in the atmosphere began increasing from March with N_o at 326 N-units and rose to a peak value of 379 N-units in August where it began to fall steadily to October until a sharp fall was observed from November at 324 N-units to 319 N-units in December. The drop continued till January 2009 and into February 2009 at 314 N-units respectively. By March, a steady increase was observed and continued till August and September at 389 N-units before it dropped sharply in November from 373 N-units to 311 N-units in December.

At Nsukka station, N_o was low in January with 327 N-units and continued into February with 324 N-units. A sharp rise was observed by March to 373 N-units indicating high level of humidity in the air due to increase in rainfall activity for the year under study. As expected, the N_o values increased steadily to a peak value of 388 N-units in October with a little break in September and November. By December, the rain had returned with N_o values increasing from 379 N-units in November to 386 N-units in December. By January 2009, N_o value dropped slightly to 380 N-units and increased slightly in February to 391 N-units after which it dropped to a low value of 324 N-units in April. By May, N_o value increased from 397 N-units to a peak value of 399 N-units in October. By November, N_o value dropped from 366 N-units to 337 N-units in December signifying the commencement of the dry season for the zone.

It was observed that there was no sharp decline in N_o values from November and December for Nsukka unlike what was observed in the other two stations under study. Also in Akure, the harmattan period was observed to end in January while for the other zones, the harmattan continued way into February. On the average, Nsukka experienced more rainfall activity than any of the regions under study.

4.3 Annual Variation of Reduced–to–Sea–Level Value Refractivity in the Three Stations from 2008 – 2009

As shown in Table 2, the annual minimum value was observed in Minna over the two years of this study while Akure recorded the maximum value in 2008 and Nsukka has the maximum in 2009 respectively. In summary, the mean value of 376.15, 352.72 and 376.21 were deduced for Akure, Minna and Nsukka respectively. The minimum value observed in Minna can be attributed to low rainfall activities which culminates into low humidity in the region. This is because humidity decreases from coast inland.

5. Conclusion

Two years measured tropospheric parameters **of** pressure, temperature and humidity covering a period of January, 2008 – December, 2009 were used for the determination of surface refractivity and its reduced – to – sea – level value at each of the three different stations under study namely: Akure, Nsukka and Minna.

The study revealed that the surface refractivity varies with the time of the day as well as the seasons of the year with high values recorded in the morning and evening hours. Higher values of surface refractivity and reduced – to – sea – level value refractivity were observed for Nsukka, in South-eastern Nigeria and Akure, in South-western Nigeria for the period under study compared to corresponding low values in Minna, in North-central Nigeria. An average surface refractivity of 357.19 N-units, 351.09 N-units and 358.86 N-units were obtained for

Table 2: Average annual variation of surface refractivity, Ns and its reduced-to-sea-level, Ns value at the three stations for years 2008 - 2009

Station/Year	**2008**		**2009**		**Mean**	
	$\mathbf{N_s}$	$\mathbf{N_o}$	$\mathbf{N_s}$	$\mathbf{N_o}$	$\mathbf{N_s}$	$\mathbf{N_o}$
Akure	358.91	377.92	355.48	374. 38	357.19	376.15
Minna	352.12	346.76	350.06	358.68	351.09	352.72
Nsukka	359.89	372.29	357.84	380.12	358.86	376.21

Akure, Minna and Nsukka respectively. The obtained values are within the range of 350 and 400 N-units for which this propagation zone is classified as sub-tropical savannah.

The seasonal variations of surface refractivity and its reduced – to – sea – level value have important implications on radio propagation. Thus, the knowledge of the variability pattern of radio horizon distances in parts of the study areas will enable the microwave circuit engineer determine optimal transmitter heights required to achieve desired coverage in such areas.

Acknowledgements
The author is grateful to the following organizations: Centre for Atmospheric Research of the National Space Research and Development Agency (NASRDA) located at the campus of Kogi State University, Anyigba, Kogi State, Nigeria for donation of equipment, Alexander von Humboldt Foundation for equipment donation, University of Bonn, Germany for research collaboration and the Nigerian Television Authority (NTA) for the use of its facilities.

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