Journal of the Nigerian Association of Mathematical Physics
***Volume* 20 (March, 2012), pp 309 – 314**
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Variation in Primary Radioclimatic Variables, And Its Effects on Radio Signal Propagation at the Lower Troposphere.

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Abstract

Radio refractivity and refractive index are important radioclimatic parameters that influence radio wave propagation. The impact of these variables depends on the variation of the measured data of the primary radioclimatic parameters (temperature, relative humidity and atmospheric pressure) with height at lower troposphere. The data of the study was collected via two wireless weather station using Vantage pro2, one stationed at ground surface while the other is at 100 m height in Nsukka (7.30^{o}E, 6.45^{o}N). The study covers twelve months of which the data collected was used to compute the values of the variables and the effect in the variability on radio signal propagation. The result shows that refractive index decrease with an increase in height and thus, refractivity gradient also decrease from normal – 40 dN / Kilo meter to – 127 dN / Kilo meter for eleven months, thereby resulting to super- refraction propagation condition, while in one month the refractivity gradient increases from normal value – 40 dN / Kilo meter to – 28 dN / Kilo meter which cause sub-refraction. Clearly, all these results affect radio wave propagation which limits its reception in Nsukka, South-East, Nigeria.

Keyword: Refractivity Gradient, Index of Refraction, Signal Fading, and Propagation Conditions.

1.0 Introduction

Atmospheric properties help in solving problems that arise in radio wave propagation and predicting path reliability. Radio waves may bend while propagating via different atmospheric layers due to the changes of refractivity. These changes are determined by atmospheric conditions, mainly temperature, humidity, and atmospheric pressure; furthermore, all these vary with the geographical location, time and season [1]. Thus, the troposphere is characterized by a steady decrease in both temperature and pressure as height increases. In effect, the air in the troposphere is in constant motion which lead to eddies or turbulences, and is highly intense near the Earth's surface, resulting to refraction and scattering of radio waves with short wavelength and enhanced communications at higher frequencies. Signals using frequencies at VHF (30 – 300 MHz) are affected by weather conditions in the troposphere. These signals are refracted as a result of the variation in refractive index occurring in the troposphere, which causes the signals to travel beyond the line-of-sight (LOS) radio link [2]. However, signal subjected to slow deep fading are cause by propagating signal via the troposphere in different paths to the receiver, and the movement of air at the lower troposphere changes the signal propagation paths periodically. This made the signals appearing at the receiver to fall in and out of phase with each other, thereby affecting the strength of the overall received signal.

Therefore, previous study in regards to radio communication problems are based on small changes in the vertical distribution of radio refractivity and atmospheric profile variation with altitude [3,4,5,6, and 7].

The study by [8] at Nsukka contains good results on surface radio refractivity during dry and wet seasons for twelve months but the study did not discuss the propagation effect on radio signal over Nsukka.

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Therefore, this work focuses on the effects of secondary radioclimatic variables with altitude, on line-of-sight (LOS) link design in radio communication in Nsukka, South-East Nigeria.

The study present interesting results of refractive index, radio refractivity distribution and its refractivity gradient that was used to estimate the radio signal propagation effect over Nsukka. Thus, the research finding is vital for future use, for instance, in the designing and constructing of suitable communication gadgets in Nigeria, so that signal fading can be minimized in an area like Nsukka, South-East of Nigeria.

2.0 Theoretical Review:

The effects of signal fading on radio communication systems in rural and urban areas in Nigeria, lead to the need of investigating the impact of some of the secondary radioclimatic parameters in this area of study. These parameters depend on the physical features of the area and the geographical location in respect to the communication distance or radio transmission.

2.1 Radio Wave Propagation

Radio waves are affected by the phenomena of reflection, refraction, diffraction, absorption, polarization, scattering and also by daily changes of water vapor in the troposphere. Radio waves consist of electric field and magnetic field. The electric lines of force and the magnetic lines are at right angles to each other and to the direction of propagation. The propagation medium for short distance communication could be anything but for long distance is free space. In the process of propagation over the horizon, the radio signals at the troposphere refract, bend, scatter, and reflect the electromagnetic field. The density and index of refraction are highest near the surface, and steady decrease with altitude. That is why radio wave at VHF (**30-300 MHz**) and UHF (**300 MHz-3 GHz**) refracts towards the surface.

2.3 Tropospheric Scattering Propagation

Troposcatter occurs when radio wave meets turbulence in the troposphere, its velocity changes and lead to scattering of some energy in a forward direction which returns to Earth at distances beyond the horizon. The process repeats itself, and when the wave reaches the horizon it will be diffracted and follows the earth's curvature; hence, the rate of attenuation increases very rapidly and signals soon become very weak and unusable. The magnitude of the received signal depends on the quantity of turbulences causing scatter in the desired direction and the gain of the receiving antenna. The signal take-off angle which is the transmitting antenna's angle of radiation determines the height of the scatter volume and the size of the scatter angle. So, it is proportional to the height of the scatter volume and that decreases the received signal. As the distance between the transmitting and receiving antennas increases, the height of the scatter volume also increases, which result to the decrease in the received signal as shown in Figure 1.

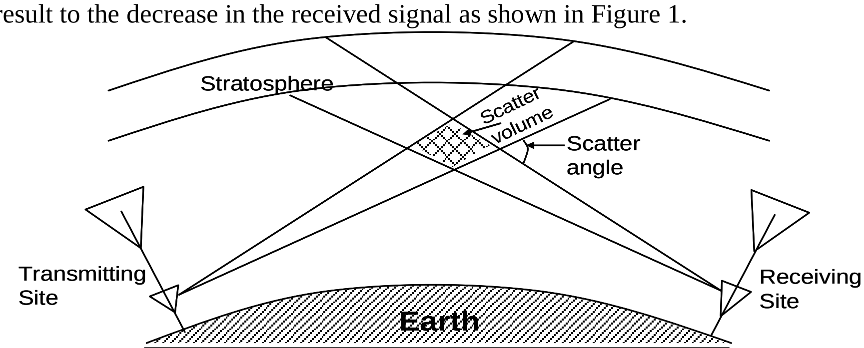

Fig 1. Tropospheric scattering propagation.

2.4 Refractivity (N) and Refrective Index (N)

The refractive index of the troposphere varies according to the increase in height from sea level, which has significant effect on the radio signal [9]. The fall in refractive index with respect to height is governed by the speed of propagation in a medium, which is given in the electric field in space and time equation as

$$\mathbf{E(r,t)} = \mathbf{E_o} e^{i(n(r)kr - wt)} \quad \textbf{(1)}$$

where k is a vector normal to the wave front, and ω is the angular velocity.

Thus, the relationship between refractivity and index of refraction are obtained by the equation proposed [10]

$$\mathbf{n = 1 + N \times 10^{-6}} \quad (2)$$

where **n** is the refractive index and **N** is the radio refractivity. Therefore, the procedure of International Telecommunication Union **(ITU)** recommendation for determining the refractivity based on the measured values of the atmospheric profile temperature, pressure, and relative humidity [11] is given by

$$N = N_{dry} + N_{wet} = \frac{77.6}{T}\left(\frac{P + 4810\,e}{T}\right) \quad (3)$$

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

$$N_{wet} = \frac{77.6 \times 4810e}{T3}$$

where **P** is the pressure (hpa), **T** is the absolute temperature **(K)** and **e** is the water vapor pressure (hpa).

Thus, the refractivity gradient is a determinant of the variations of refractive index with altitude. The change in radio refractivity per kilometer height is given

$$\frac{\Delta N}{KM} = \frac{N\text{s} - Ni}{0.1} \quad (4)$$

where N_s is the refractivity at the surface of the earth and N_i is that at a height of **100 m** above the surface of the earth. Hence, variation in the atmospheric profiles causes significant deviations in the lapse rate. Values of ΔN per Kilo meter that are less than - 40 ΔN per Kilo meter cause sub-refraction and greater than – 40 ΔN per Kilo meter cause super-refraction. If the decrease of ΔN per Km exceeds – 157 ΔN per Km, then the radio wave will follow the curvature of the earth in a phenomenon known as ducting.

However, the relationship between saturated vapor pressure and relative humidity is used to calculate the water vapor pressure using the expression

$$e_s = \frac{100\,e}{H} \quad (5)$$

but, e_s can be expressed in the relationship with temperature as

$$e_s = 6.1121 \exp\left(\frac{17.502\,t}{t + 240.97}\right) \quad (6)$$

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).**

3.0 Experimental Procedure

Some of the secondary radioclimatic variables can be measured directly by the use of refractometer or radiosonde . The refractometer is preferred due to its high precision and accuracy but because of the cost of acquiring one, it's relatively complex in the design and also the demand of high skill handling, the instrument is less used. While for the radiosonde , it can only measure up to **10 km** above the earth surface and has poor spatial and temporal resolutions. Therefore, the indirect means of measuring the atmospheric profile such as atmospheric pressure, relative humidity and temperature at earth surface and **100 m** height was applied. The measurement was done using two wireless Vantage pro2, automatic weather station installed at Center for Basic Space Science (CBSS) and NITEL mast Nsukka. The instrument comprises Integrated Sensor Suite (ISS) and wireless Console with data logger and as well a personal computer for downloading the data.

3.1 Method Of Measurement

The ISS was fixed at two different positions; one at ground level which measures the primary radioclimatic parameters, for the computations of surface refractivity and refractive index while the second one was installed at 100 m height on NITEL mast of about 250 m high at Nsukka town, for the calculations of radio refractivity at 100 m height and refractive index.

The measurement covers 24 hours each day beginning from 12.00 am local time and for a time interval of 30 minutes. The data used for this work covered both the wet and the dry seasons in Nsukka region. The dry season is mainly from late October to March while the wet season months are from April to early October of the year.

Thus, the data collected was transmitted to the wireless console and it is attached with data logger serving as storage device, it operate at a frequency of **860MHz,** ITU-R (1970-1999).

Thereafter, the data logger is then connected to a computer either by USB data logger connector or USB-to-USB connector cable and the data is downloaded for the calculations of the secondary radioclimatic parameters using the equations (1 – 6) above. Meanwhile, the ISS has an error margin for the atmospheric profile as **±0.1^{o}C, ±0.5hpa,** and **±2%**, respectively for temperature, pressure and relative humidity. However, several precautions such as the mechanical and electrical connections and installations were taken to enhance the accuracy of the results.

4.0 Results and Discussion

The results of the study are presented graphically in Fig. 2 – 4 and in Table 1. The variation of monthly mean value of Refractivity at the ground level and at 100 m height from June 2010 to May 2011 is shown in Figure 2.

In the graph, both plots have the same trend of full cycles in over the months of climatic seasons in the area. The refractivity of both levels gradually increases from January to February and decreases sharply in March and April. The sudden decrease is attributed to the decrease in atmospheric pressure and temperature and an increase in relative humidity, which mark the beginning of rainy season in the region. Thereafter, the Refractivity increase till June and then decrease gradually and later rises to the peak in October and December. The high values of refractivity in these months

are due to the peak period of raining season in the month of June, the beginning of dry season in the month of October, and the introduction of hamattan in the month of December attributed to its rise.

Therefore, large difference in the value of refractivity at zero level and at 100 m level between May, June, August to October and the month of December, might be attributed to the variation of seasons in relation to the movement of the Inter-Tropical Discontinuity that separate the warm and moist winds from the warm and dry winds at the earth surface.

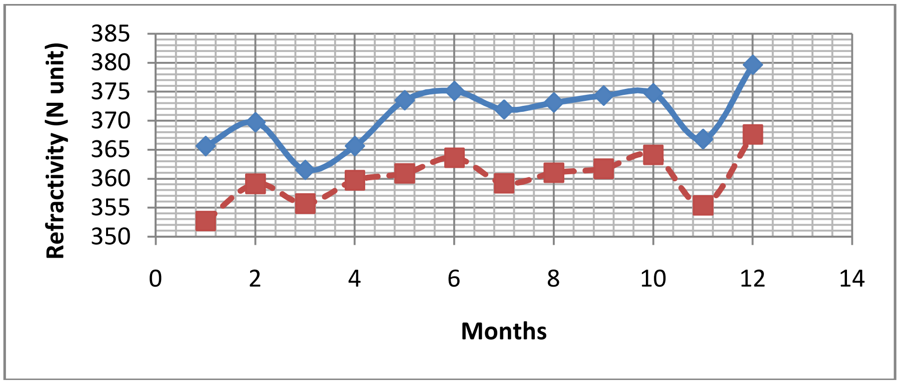

Figure 2: The Changes of Monthly Average Value of Refractivity at Ground Level and 100m level from June 2010 to May 2011 in Nsukka South-East Nigeria. The dotted curve shows the Refractivity at 100m level and the non-dotted curve is that of Ground Refractivity.

In Figure 3, it was observed that at N_g = 369.7, the corresponding value of dN/ km = -24, in the month of February and the highest value of dN/ km = -127 and its equivalent value of N_g = -371.9 in the month of July. Therefore, the limiting value of dN / km equals to -157 that corresponds to 550 N_g was not observed. Thus, the latter value is rarely encountered in practical applications.

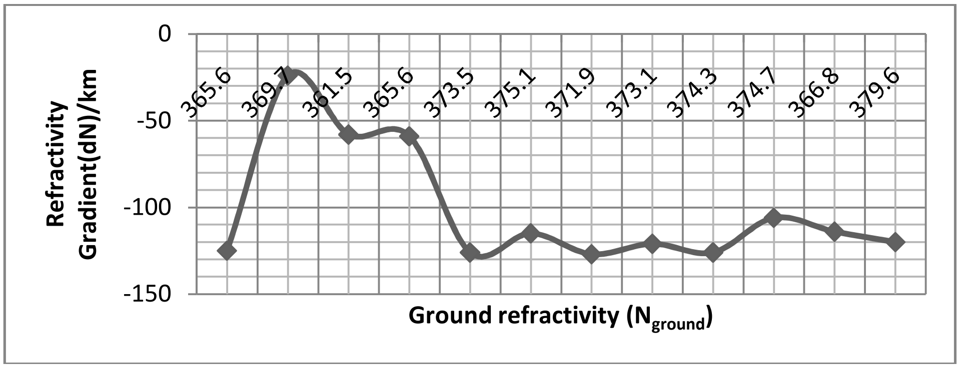

Figure 3: A plot of Refractivity Gradient versus Ground Refractivity.

In Figure 4, super-refraction propagation condition is prevalent for eleven months except in the month of February. In those months, refractivity gradient is < - 40 dN/km and this condition causes the signals transmitted to bent downward towards the earth, resulting to signal skip beyond the point of target or line- of- sight due to multiple reflections. The cause of the condition is the rise of temperature with increasing height or a marked decrease in total moisture content in the air. Either of which will cause a decrease in the dielectric constant gradient with height.

But in February, refractivity is -24 dN/km, indicating sub- refraction in Nsukka and there will be reduced radio horizon and this effect may lead to frequent signal outage within the town. Also, ducting was not experienced.

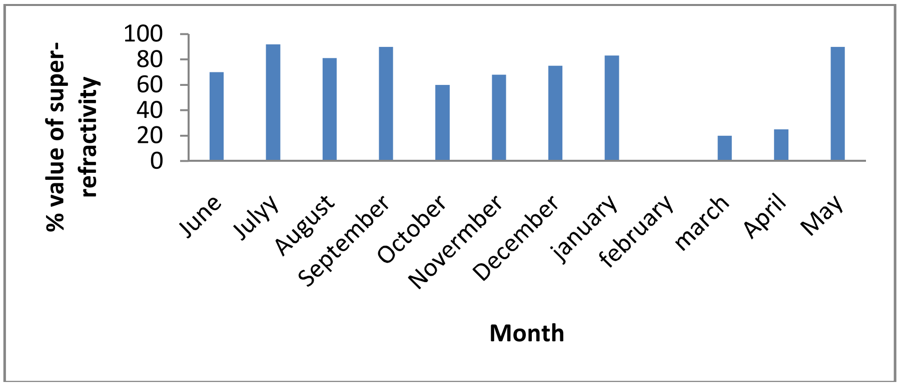

Figure 4: Chart Representing the Obtainable percentage value of Super-refractivity Condition in Nsukka at 100m height.

Results obtain in Table 1, shows the increase in the values of refractive index between the months of (April – October). These months are within the wet climatic season in the zone, and the cause of this high values are because of increase in relative humidity due to heavy amount of moisture in the atmosphere. Thus, the values of the remaining months were also affected due to the dry / harmattan season. From late November to January, harmattan sets in and the atmospheric pressure and the relative humidity decreases. Also, the decrease in the refractivity gradient in the months of February – April window is mainly due to the dry season and the emergence of the rainy season which causes increase in temperature.

Thus, anomalous propagation may be experienced within the periods of June and July because of high rain fall. The changes in the primary radioclimatic variables lead to the abnormal changes in refractive index which can cause the radio waves to propagate much further than normal, affecting the reception of radiowave signal in the region.

Table 1. Monthly mean Data and the calculated secondary Radioclimatic Parameters at a Height of 100m level at NITEL Mast in Nsukka town and Ground level Measured Data at (CBSS), University of Nigeria, Nsukka from June 22nd, 2010 to May 13th, 2011

		100m level measurement				Surface level measurement			
MONTH	DAILY TIME	AVE. TEMP (°C)	AVE. HUM (%)	AVE. PRESS. (Milibar)	n	AVE. TEMP (°C)	AVE. HUM (%)	AVE. PRESS. (Milibar)	n
JUNE	12am - 11.30pm	23.1	91.0	968.4	1.000364	23.7	88.3	1014.2	1.000375
JULY	12am - 11.30pm	22.5	90.9	967.2	1.000359	23.5	87.1	1012.6	1.000372
AUGUST	12am - 11.30pm	22.4	92.6	965.7	1.000361	23.2	89.3	1012.4	1.000373
SEPTEMBER	12am - 11.30pm	22.6	92.6	964.4	1.000362	24.5	85.4	1011.0	1.000374
OCTOBER	12am - 11.30pm	25.2	83.6	966.9	1.000364	25.6	81.8	1010.0	1.000375
NOVEMBER	12am - 11.30pm	25.4	76.8	965.2	1.000355	25.7	75.8	1009.2	1.000367
DECEMBER	12am - 11.30pm	25.9	83.0	969.9	1.000377	27.3	77.9	1016.0	1.000380
JANUARY	12am - 11.30pm	25.4	75.0	964.7	1.000353	25.8	74.0	1010.4	1.000365
FEBUARY	12am - 11.30pm	26.6	75.2	965.9	1.000359	27.4	71.8	1011.4	1.000370
MARCH	12am - 11.30pm	26.0	75.4	963.0	1.000356	26.5	73.2	988.9	1.000362
APRIL	12am - 11.30pm	24.9	82.1	962.9	1.000360	25.1	81.1	986.6	1.000366
MAY	12am - 11.30pm	25.1	82.0	964.9	1.000361	25.9	79.5	1010.7	1.000374

5.0 Conclusion

The results of the study show that the refractive index is apparently high within the period of rainy season and in the months of early dry season and harmattan period. This shows that the temperature, pressure and relative humidity has more effect on these months than the remaining months.

Also, the propagation conditions observed has two degree of occurrence, with super-refraction condition prevalent for eleven months, while Sub-refraction occur only in one month, and ducting was not observed.

However, this study is continuous in other to have well recorded database for future planning and predicting radio wave propagation problems in the Eastern region of the country Nigeria.

From the results, it shows that super-refraction is common in the region, except in one month that sub-refraction occurred. So, to minimize the effects, the communication companies in Nigeria should study and get reliable atmospheric data in relation to the location they will install their mast. This is because in a place like Nsukka, the height and angle of tilt of the antenna in the mast should be considered to avoid signal fading in the area. Also, the Nigeria communication commission (NCC) collaborating with National Center for Basic Space Science (NCBSS) and other agencies should try as much as possible to be working in hand with the companies designing and constructing the communication gadgets used in Nigeria with our local atmospheric profile data, in order to prevent loss of signal and also money wasted as a result of signal fading or drops due to environmental condition.

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