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Study of the Radio Refractivity Over Awka, South Eastern Nigeria Using Meteorological Parameters on the Troposphere during Dry and Wet Seasons

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Abstract
Radio refractivity over Awka, South Eastern Nigeria has been studied using meteorological parameters on the troposphere during dry and wet seasons, from 2013 – 2014 respectively. Wireless weather stations (Integrated Sensor Suite, ISS) were positioned at five different height levels beginning from the ground surface and at intervals of 50 m from the ground to a height of 200 m (0, 50, 100, 150 and 200 m). The data used for the computation of radio refractivity and refractivity gradient is a 30 minutes interval variation of metrological parameters for each day in the troposphere over Awka. Hourly, daily and monthly averages of radio refractivity during dry and wet seasons were calculated from the data obtained. The result indicated that the radio refractivity during wet season is greater than the result obtained during dry season. This was as a result of variation in meteorological parameters such as relative humidity and temperature, which causes the radio refractivity to vary at different times of the day, while the pressure variation seems to be insignificant. However, results of the refractivity gradient show that the propagation conditions have varying degree of occurrence. Also, the sub-refractive conditions were observed to be prevalent between January–May and August to December. Finally, Super-refraction was observed mostly between June and July respectively.

Keywords: *Radio Refractivity, Refractivity Gradient, sub-refractivity, super-refractivity and Troposphere.*

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I. Introduction

Radio frequency or radio wave signal propagation in the troposphere is affected by many factors caused by the variations of metrological parameters such as humidity, temperature and atmospheric pressure. This can be reflected, refracted, scattered, and absorbed by different atmospheric constituents. The part of atmosphere most closely related to human life is troposphere; it extends from the earth surface to an altitude of about 10 km at the earth's poles and 17 km at the equator. The degree of atmospheric effects depends mainly upon the frequency, power of the signal and on the state of the troposphere through which the radio wave propagates. The characterization of tropospheric variability has great significance to radio communications, aerospace, environmental monitoring, disaster forecasting, etc. For instance, worse propagation conditions may lead to increased fading on communication links and consequently decreased power levels at receiver. Quality of propagation of radio waves between the transmitter and receiver mostly depends on performance and reliability of the link. Also, a radio propagation model is required to be used for the evaluation of signal level variations that occur at various locations of interest over different times of the year.

An important element of such type of radio propagation model is the variation of radio refractivity in the troposphere. It was observed that sometimes, microwave systems could become unavailable due to seasonal variation of refractive index (Serdega and Ivanovs, 2007). Therefore, the accurate knowledge of radio refractive index of the lower atmosphere is important in the planning and designing of terrestrial radio links for communication networks, radar and propagation applications (Caglar et al., 2006; Naveen et al., 2011). Any model, therefore, should take into account refractive index variations both in time and space.

The variation of refractive index is due to various phenomena affecting the propagation of radio signal, which for instance include refraction, bending, ducting and scintillation, range and elevation errors in radar acquisition and radio-station interference (Maitham and Asrar, 2003; Freeman, 2007; Jan and Ewa, 2009; Grabner and Kvicera, 2003; Tom, 2006). The variation of refractive index as well as specific attenuation of micro/radio wave may be estimated indirectly with the measurement of temperature, pressure and relative humidity. The effect of temperature and relative humidity on specific attenuation of microwave was studied by different researchers (Ihara, 1994; Tamosiunaite et al., 2010). For example, the 10% increase in temperature could increase the specific attenuation of microwave by 72.73 x 10^{-5} dB/km whereas 10% increase in relative humidity could increase the specific attenuation by 2.51 x 10^{-2} dB/km. The establishment of a radio refractive index database is necessary because the knowledge of radio refractive index is always required when measurements are made in air (Nel et al., 1988; Guanjun and Shukai, 2000; Valma et al., 2010). In the absence of reliable local data, wireless service providers use the radio refractive index and other data from world charts and global numerical maps provided by International Telecommunication Union (ITU).

Therefore, it is the intent of this study to investigate, estimate and characterize the radio refractivity variations derived from meteorological parameters over the years 2013 and 2014 thoroughly using statistical analysis, for Awka, the capital city of Anambra State, in south Eastern Nigeria.

Several research works have been carried out in different regions of Nigeria regarding Radio Refractivity. In this review of related literature, studies on the radio refractivity by different researchers were reviewed.

Adediji & Ajewole (2008), studied the vertical profile of radio refractivity gradient in Akure South-West Nigeria. Measurements of atmospheric pressure, temperature and relative humidity were made in Akure (7.15◦N, 5.12◦E), South Western Nigeria. Wireless weather stations (Integrated Sensor Suite, ISS) was positioned at five different height levels beginning from the ground surface and at intervals of 50 m from the ground to a height of 200 m (0, 50, 100, 150 and 200 m) on a 220 m Nigeria Television Authority TV tower at Iju in Akure North Local Government area of Ondo State. The measurement of the atmospheric variables was made every 30 minutes every day. The study utilized the data for the first year of measurement (January–December 2007) to compute the radio refractivity and its refractivity gradient in Akure. From these parameters, the vertical distributions of radio refractivity was then determined. The results obtained showed that the propagation conditions have varied degree of occurrence with sub-refractive conditions observed to be prevalent between January–July while Super-refraction and Ducting were observed mostly between August–December.

II. Theory of Radio Refractivity

Radio-wave propagation is determined by changes in the refractive index of air in the troposphere. Because it is very close to unity (about 1.0003), the refractive index of air is measured by a quantity called the radio refractivity N, which is related to refractive index, *n* as (ITUR, 2003):

$$n = 1 + N\,x\,10^6 \quad \text{..........} \quad (1.1)$$

In terms of measured meteorological quantities, the refractivity *N*, can be expressed as:

$$N = 77.6\frac{P}{T} + 3.73 \times 10^5\,\frac{e}{T^2} \quad \text{..........} \quad (1.2)$$

Where: p = atmospheric pressure (hPa),
e = water vapour pressure (hPa) and
T = absolute temperature (K).

Equation (1.3) may be used for radio frequencies up to 100 GHz. The error associated with the use of this expression is less than 0.5% (ITU-R, 2003). The water vapour pressure e is usually calculated from the relative humidity, and saturated water vapour, using the expression:

$$e = H\,x\,\frac{6.1121\exp\left(\frac{17.502t}{t+240.97}\right)}{100} \quad \text{..........} \quad (1.3)$$

Where: H = relative humidity (%),
t = temperature in degree Celsius (^{0}C) and
e_s = saturation vapour pressure (hPa) at the temperature t (^{0}C).

The vertical gradient of refractivity in the lower layer of the atmosphere is an important parameter in estimating path clearance and propagation effects such as sub-refraction, super-refraction, or ducting according to the following criteria:

I. Sub – Refraction: $\frac{\partial N}{\partial z} > -40$

Refractivity *N* increases with height and in this case (sub-refraction), the radio wave moves away from the earth's surface and the line of sight range and the range of propagation decrease accordingly.

II. Super - Refraction: $\frac{\partial N}{\partial z} < -40$

During super-refractive conditions, electromagnetic waves are bent downward towards the earth. The degree of bending depends upon the strength of the super-refractive condition. On reaching the earth's surface and being reflected from it, the waves can skip large distances, thereby giving abnormally large ranges beyond the line of sight due to multiple reflections.

III. Ducting: $\frac{\partial N}{\partial z} < -157$

During ducting phenomenon, the waves bend downwards with a curvature greater than that of the earth. Radio energy bent downwards can become trapped between a boundary or layer in the troposphere and the surface of the earth or sea (surface duct) or between two boundaries in the troposphere (elevated duct). In this wave guide-like propagation, very high signal strengths can be obtained at very long range (far beyond line-of-sight) and the signal strength may exceed its free-space value.

III. Materials and Methods

This study was carried out at the permanent site of the Nnamdi Azikiwe University, Awka (Fig 3.1), in Awka South local government area of Anambra state. It is about 17 km by road away from the city of Awka, with coordinates, (6°12′25″N 7°04′04″E) (Fig. 1.2)

Fig 1.2: Study Location (Nnamdi Azikiwe University, Awka)

Fig 1.3: The Integrated Sensor Suit (ISS) on site at Awka

The instrument used for this measurement was the Davis 6162 Wireless Vantage Pro2 equipped with the Integrated Sensor Suite (ISS) (Fig.1.3), a solar panel (with an alternative battery source) and the wireless console. The console was connected to a computer, through which the stored data were downloaded. The ISS houses the sensors for pressure, temperature, relative humidity, UV index and dose, solar radiation and the sensor interface module (SIM) among others. The SIM contains electronics that measure and store values of weather variables from transmission to the console via radio. The fixed measuring method by a high tower was employed for the measurement with the ISS positioned on the ground surface of the tower (Fig. 1.2) for continuous measurement of the atmospheric pressure, air temperature and relative humidity. The TV tower carrying the ISS is 220 m high. The measurement covers 24 hours each day beginning from 00 hours local time (LT) and for a time interval of 30 minutes. The data was then transmitted by wireless radio connection to the data logger attached to the console which is located in-door on the ground. The data were then copied to the computer for analysis. The error margin of the ISS device for temperature, pressure and relative humidity are ±0.1◦C, ±0.5 hpa and ±2% respectively.

IV. Method of Data Analysis

In relation with the measured meteorological parameters by the Solar Energy option of Physics and Industrial Physics department, Nnamdi Azikiwe University Awka, such as the temperature, pressure and relative humidity, radio refractivity values for both the dry and well wet seasons in Awka was calculated using refractivity expression in equation (2), to give the data point representing diurnal variation for twelve months of the each study year.

$$N = 77.6\ P/T + 3.73 \times [10]^5\ (e)/T^2$$

As previously stated in equation (8) and (9), radio refractivity of the lower atmosphere (troposphere) is divided into two compositions; which are shown in the following expressions;

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

$$N_{wet} = 3.73 \times [10]^5\ (e)/T^2$$

The two expressions above were used to compute the radio refractivity for dry and wet seasons respectively, which in turns used to calculate the total radio refractivity for every measurement period. From the two equation, we obtain;

$N = N_{dry} + N_{wet}$ ………………………………………………………. (1.4)

The average variation of each hour per day was calculated from the recorded data. Hence, the partial vapour pressure was determined from the equation as follow:

$e = e_s H/100$ ……………………………………..……...……………. (1.5)

Where H is the relative humidity, and e_s is the saturation vapour pressure determined by Clausius – Clapeyron equation given as:

$e_s = 6.1121\exp[(17.02T/(T+240.97)]$ …………..…………….……… (1.6)

Furthermore, the refractivity gradient G (change in refractivity with height) at the surface was determined using the expression;

$DN/dh = -7.32e\text{^}(0.005577\, N_s)$ ………………………………….…... (1.7)

Where N_s is the radio refractivity at the ground surface

V. Results

Results obtained during this study were properly analyzed and presented in the figures below.

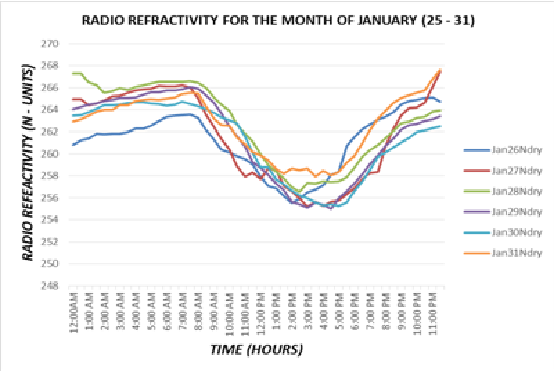


Fig. 1.4: *Hourly Variation of the dry term contribution of Radio Refractivity over Awka for the month of January (25 - 31) in dry season*

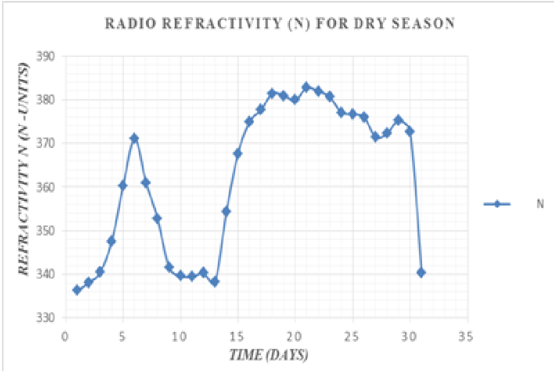
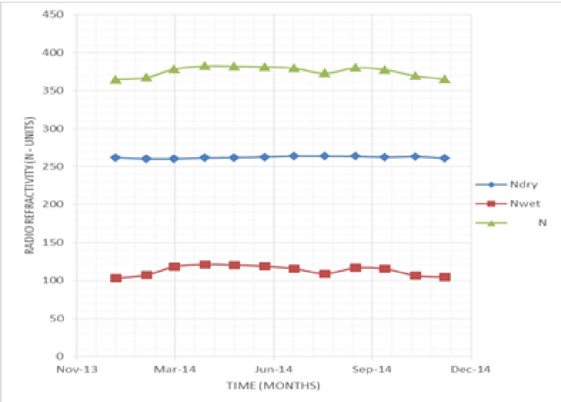


Fig. 1.5: *Daily Variation of Radio Refractivity over Awka for the month of January (1 - 31) in dry season*



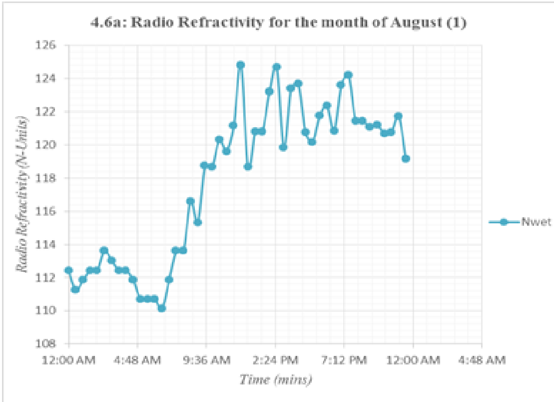
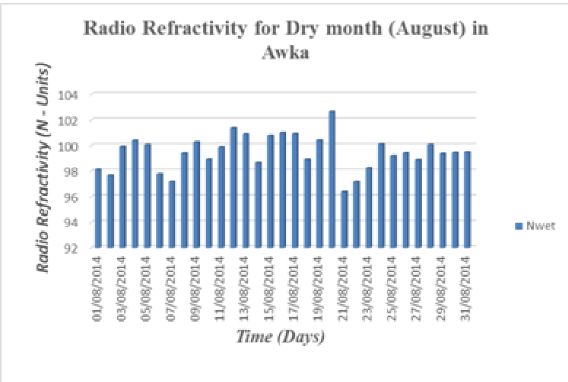


Fig. 1.6.: *Mean of monthly radio refractivity for 2013*

Fig. 1.7.: *Radio Refractivity for the month of August 2014*



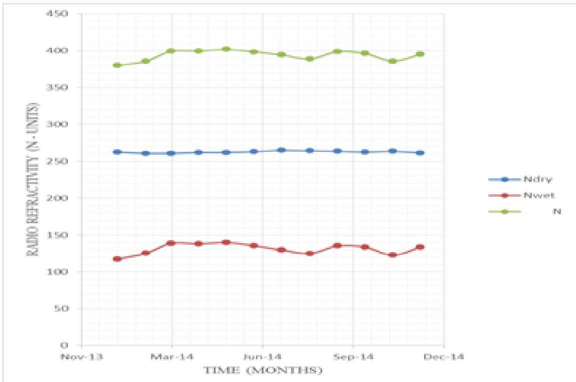


Fig. 1.8: *Daily mean variation of radio refractivity for wet season (August 2014)*

Fig. 1.9: *Mean of monthly radio refractivity for 2014*

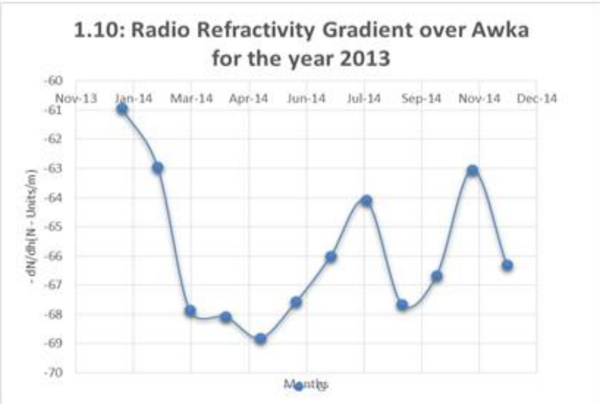
Fig. 1.4 shows that the refractivity *(N)* increased uniformly from 12:30AM to 7:00AM Local Time to a value of 271.9N - units and a uniform decrease in the value of radio refractivity was observed at about 8:00PM to 5:30PM Local Time for the month of January in dry season to a value of 254.5N – units (dry term).

For the dry term in fig. 1.5, the lowest refractivity of 336 N – units was observed on the 1st day of the month, after which it increased steadily to the value of 371.5 N-units on 6th day, while the highest refractivity of 383N-units was observed on 23rd day in the month of January.

In fig 1.6 and 1.9 respectively, the results were computed from hourly, daily and monthly average values. From the plots, it is observed that the dry season months (January - March) in both figures have low refractivity values ranging from a total average of 360.5 N – units to about 375.5 N – units for the two years period. Also, during these months, it is evident that large daily ranges and variability of the radio refractivity *N* are displayed.

Fig. 1.7 shows hourly variation of the wet term contribution of Radio Refractivity over Awka for the month of August in wet season. In fig 4.6a, the results revealed that the radio refractivity increased progressively to a maximum point of refractivity of 249.5N – units at 11:09AM. The minimum value of refractivity was observed at 6:49AM with refractivity value of 111.5N - units. These two figures (4.5a and 4.5b) have similar characteristics with those obtained in 2013 for the wet months.

Figures 1.8 shows the results of the average daily radio refractivity for the year 2014 over Awka, Nigeria, for both the dry season (January) and the corresponding contributions of the wet season (August). In fig peak refractivity value here is ~265N – units while the least value is 252.1N – units. But in fig 4.7b, the peak refractivity value is 102.65N – units. From the two figures, it is observed that the dry month (January) shows least variation compared to the wet month (August). However, the Refractivity values are found to vary between 356 N – units and 362 N – units.



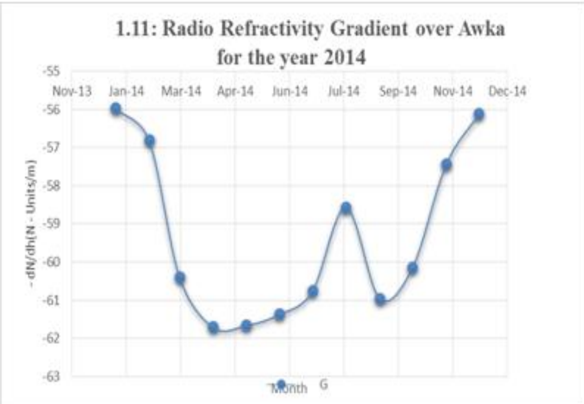


Fig 1.10 and 1.11 shows Radio Refractivity Gradient over Awka for the year 2013 and 2014 respectively. The average monthly refractivity gradient dN/dh from 2013 to 2014 over Awka was calculated and found to vary from -55.97 N – units/m to -68.07 N – units/m for the dry season periods and -57.44 N – units/m to -68.81 N – units/m for the wet season periods.

The figures also show that the monthly variations of refractivity gradient gives large negative values in January corresponding to the period of intense harmattan observed around Awka which is often characterized by very cool nights and morning times and very dry day time. The average value of refractivity gradient for year 2013 is -65.83 N – units/m and -59.33 N - units for the year 2014. From these average values, it could be deduced that propagation condition in this geographical zone is mostly super – refractive.

Finally, it was revealed that propagation condition appeared to be more super - Refractive in the months of April and May in Awka, with refractivity gradient ranging from -68.07 N – units/m and -68.81 N – units/m respectively.

VI. Conclusion

Radio refractivity over Awka, South – Eastern Nigeria, has been investigated and the result has been presented as well. Results shows that variations in weather are more significant during the rainy season than the dry season in Awka, owing to the increase in the tropospheric temperature and humidity, and it therefore resulted to very high radio refractivity within that period.

Based on the analysis, the following conclusions were made:

1. The hourly variation of radio refractivity seems to be mainly driven by the dry component in the rainy season and the wet component in the dry season.
2. The radio refractivity over Awka shows a seasonal variation with high values in the rainy season and low values in the dry season.
3. The wet season is highly variable unlike the dry season's refractivity which has small variability.
4. The average value of radio refractivity gradient over Awka for the year 2013 is -68.07 N – units/m and -68.81 N – units/m for the year 2014 with an average value of -68.44 N – units/m for the two years period of the report.
5. For microwave propagation in Awka and its environment, the propagation condition could be mostly super – refractive. But the months of April/May has the highest value of refractivity gradient.
6. It is recommended that further investigation should be carried out to test the relationship between radio refractivity and radio signal propagation for both dry and wet season using this systematic approach that have been developed and employed in this research work. This will help in determining the radio signal strength over the region, as the refractivity varies.
7. Additionally, investigation should be made on the effective earth radius factor (*k-factor*) for more understanding of the variations of refractivity gradient for accurate prediction of fading or interference signals.
8. Data and information presented in this research work provides the necessary database for the prediction of microwave communication impairment in the South-East region of Nigeria; however, the measurement is continuing.
9. The knowledge gained from this task is passed to radio engineers so as to aid them enhance and improve their methods for predicting electromagnetic radio propagation.

Acknowledgements

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