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The Study of Surface Radio Refractivity in Awka, South Eastern Nigeria

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Authors' contributions

This work was carried out in collaboration between both authors. Author OCC designed the study, wrote the protocol and wrote the first draft of the manuscript. Author IUC managed the literature searches, analyses of the study performed the spectroscopy analysis and managed the experimental process. Both authors read and approved the final manuscript.

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ABSTRACT

This work investigates the radio refractivity over Awka, South Eastern Nigeria using meteorological parameters of surface air temperature, pressure and relative humidity collected from 2013 – 2014 respectively, using Davis weather station vantage pro 2 (with Integrated Sensor Suite, ISS) positioned close to the ground surface. The data were logged at 30 minutes interval continuously for each day during the period. 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 the wet season is greater than the dry season. This is as a result of variation in meteorological parameters such as relative humidity and temperature which cause 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 shows, that the propagation conditions have varying degree of occurrence with super-refractivity conditions observed to be prevalent throughout the two year period. The month of January has the highest value of refractivity gradient

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while least of about -63 N- units per km occurred in July and propagation implication bearing in mind that the lower the gradient (that is more negative) the more super refractive is the troposphere, and the better the propagation conditions. The results obtained from this work is useful to radio engineers for improving VHF/UHF terrestrial links based on clear- air considerations.

Keywords: Radio refractivity; meteorological parameters; refractivity gradients; troposphere.

1. INTRODUCTION

Signal propagation in the troposphere is affected by many factors caused by the variations of meteorological parameters such as humidity, temperature, and atmospheric pressure. The Radio signal can be reflected, refracted, scattered, and absorbed by different atmospheric constituents. The part of the atmosphere most closely related to human life is the troposphere: it is the lowest layer of earth's atmosphere and site of all weather on earth. The troposphere extends from the earth's surface to an altitude of about 10 km at the earth's poles and 17 km at the equator. Since temperature decreases with altitude in the troposphere, warm air near the surface of the earth can rapidly rise replacing the cold dense air at the upper part of the atmosphere. By so doing convection current is set up in the air molecules of the troposphere. Such vertical movement or convection current creates clouds and ultimately rain from the moisture within the air, and gives rise to much of the weather which we experience. The troposphere is, however, bonded on the top by a layer of air called the tropopause, which separates the troposphere from the stratosphere, and at the bottom by the surface of the earth; it contains approximately 77% of the atmosphere's mass and 99% of its water vapour and aerosols.

However, the degree of atmospheric effects on Radio signals 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 the receiver. Quality of propagation of radio waves between the transmitter and receiver mostly depends on performance and reliability of the links [1]. 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 [2]. It was observed that sometimes, radio wave systems could become unavailable due to seasonal variation of refractive index [1].

Therefore, accurate knowledge of radio refractivity within the atmosphere is very significant for radio engineers to accurately predict electromagnetic radio propagation. For example, in radar applications it is widely known that gradients in the radio refractivity of the atmosphere can create ducts which guide radio propagation to very long distances, or create holes in radio coverage through which objects may travel undetected [3,4]. For characterizing a radio channel, surface (ground level) and elevated refractivity data are often required; and in particular, the surface refractivity is very useful for prediction of some propagation effects on terrestrial links. Local coverage and statistics of refractivity, such as refractivity gradient, provide the most useful indication of the likely occurrence of refractivity-related effects required for prediction methods. Moreover, this research is important to all Radio Broadcasting Services as well as Television Stations across the country or state because, it will enable radio engineers to accurately determine the quality of UHF, VHF, and SHF signals for proper design of their communication stations.

Hence, it is the intent of this research to investigate and characterize the surface radio refractivity variations derived from meteorological parameters over the years 2013 and 2014 for Awka, the capital city of Anambra State, in South Eastern Nigeria.

2. CALCULATIONS OF SURFACE RADIO REFRACTIVITY

Refractive index of air is defined as the ratio of the speed of electromagnetic radiation in a vacuum to that in the air. The refractive index *n* has a value at sea level near 1.0003 at radio frequencies, decreasing to 1 at the top of the atmosphere. The atmospheric radio refractive index, *n,* can be computed by equation 1 [5]:

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

where: N (N-units) radio refractivity expressed by [6].

$$N = Ndry + Nwet = \frac{77.6}{T}(P + 4.810\ \frac{e}{T^2})(N-units \quad (2)$$

Where the "dry term" of radio refractivity is given by:

$$Ndry = 77.6\ \frac{P}{T}(N - units) \quad (3)$$

And the "wet term" by;

$$Nwet = 3.732 \times 10^5 \frac{e}{T^2}(N - units) \quad (4)$$

Where:

P: atmospheric pressure (hPa)
e: water vapour pressure (hPa)
T: absolute temperature (K).

This expression may be used for all radio frequencies; for frequencies up to 100 GHz, the error is less than 0.5% [6].

Also, the relationship between vapour pressure *e* (hPa) and relative humidity (H. %) is given by [6]:

$$e = \frac{He_s}{100}(hPa) \quad (5)$$

Where e_s(hPa) is the saturation vapour pressure determined by Clausius- Clapeyron equation given as:

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

Radio refractivity gradient, G(N-units/km) -at the surface level, can be expressed as [7]:

$$G = \frac{dN}{dh} = -7.32\exp(0.005577N_s)(N - units/km) \quad (7)$$

Where, N_s are the values of radio refractivity at the ground surface level.

The G-value determines the type of refraction. The surface refractivity gradient at the lower layer of the atmosphere is an important parameter for the estimation of path clearance and propagation effects, such as sub-refraction, super-refraction, or ducting.

If N is constant at some height above the ground surface intervals, the non-refraction of an electromagnetic wave is observed. At standard atmosphere's temperature, air pressure and relative humidity are decreasing with height above the ground surface, and N decreases with altitude. The condition in which the temperature of the atmosphere increases with the altitude in contrast to the normal decrease with altitude is called temperature inversion. The air condition with temperature inversion can cause channels, or ducts, of cool air to be sandwiched between the surface of the ground and a layer of warm air, or between two layers of warm air. The refraction of radio waves is classified into normal refraction (whenever G = -40N-units/km), sub-refraction (G > -40N-units/km), super-refraction (whenever -41>G>-157 N-units/km), and ducting (whenever G= -157N-units/km) [8]. Despite certain differences in the classification of refraction, the basic principles are the same in all cases. The G-value is compared with the G-value of positive normal refraction (G = -40 N-units/km). As mentioned earlier, super-refraction occurs when the bending of the trajectory of propagating radio wave towards the ground surface is greater than it's bending in case of normal positive refraction. Ducting is named as exceptional super-refraction [2]. In the case of positive critical refraction, the trajectory of a radio wave is parallel to the ground surface. The ray path is important for identifying storm characteristics and for proper use of the radar data in initialization of numerical weather prediction models [2].

3. AREA OF STUDY AND DATA

This study was carried out at the permanent site of the Nnamdi Azikiwe University, Awka, 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). The topography features of the area are two ridges or cuestas lying both in a North-South direction. The ridges reach the highest point at Agulu just outside the Capital Territory.Awka is a tropical rainforest zone of Nigeria and experience two distinct seasons brought about by two predominant winds from the Atlantic Oceans and Sahara desert for wet and dry seasons respectively. Awka being a tropical region has two seasons, the wet and the dry. The wet season is characterized by heavy rainfall. It falls between the months of April and October. The dry season, on the other hand, is characterized with scanty or no rainfall and dry dust-laden atmosphere. The season lies between the month of November and March. The temperature in Awka is generally 27-30 degree Celsius between June and December but rises to 32-34 degree Celsius between January and April, with the last few months of the dry season marked by intense heat.

The instrument used for this measurement was the Davis 6162 Wireless Vantage Pro2 weather station equipped with the Integrated Sensor Suite (ISS), a solar panel and the wireless console. The console was connected to a computer, through which the stored data were downloaded. The fixed measuring method was employed for the measurement with the ISS positioned close to the ground surface for continuous measurement of the atmospheric pressure, air temperature and relative humidity. The measurement covers 24 hours each day beginning from 00 hours Local time (LT) and logs at intervals of 30 minutes. The data were 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. Two years of data spanning 2013 – 2014 were used in this work. The measured values of pressure, temperature and relative humidity at the surface were analysed for the observed readings at all local times. Further analysis was carried out by averaging the data collected for each measurement period to give twenty four hours data for the diurnal variation over each month.

Furthermore, the average data collected in 24 hours for each day was calculated. Each day was further averaged to give a data point for each month for the seasonal variation.

4. RESULTS AND DISCUSSION

From the calculated values of refractivity, refractivity gradients were then determined. The result obtained for the average of every representative dry and wet season months is presented in Figs. 1 and 2. The values were observed to be generally high during the rainy season (April _October). The high values are due to high air humidity (very close to 100%) observed in this part of the Nigeria during this period when the city of Awka is under the influence of a large quantity of moisture-laden tropical maritime air resulting from continuous migration of inter-tropical discontinuity (ITD) with the sun. Generally, when the dry and dust –laden north-east winds become dominant in December, the dry Harmattan season sets in, resulting in lower values of refractivity.

Fig. 1 shows the surface refractivity of a typical dry season month, January. Surface refractivity values rise gradually from the 1st day with a minimum value of 336 N-unit to a value of 371 N-units on the 6th day. The rise in the value of refractivity is due to higher moisture content and lower temperature. The value falls gradually to a value of 342 N-units and maintains steady values

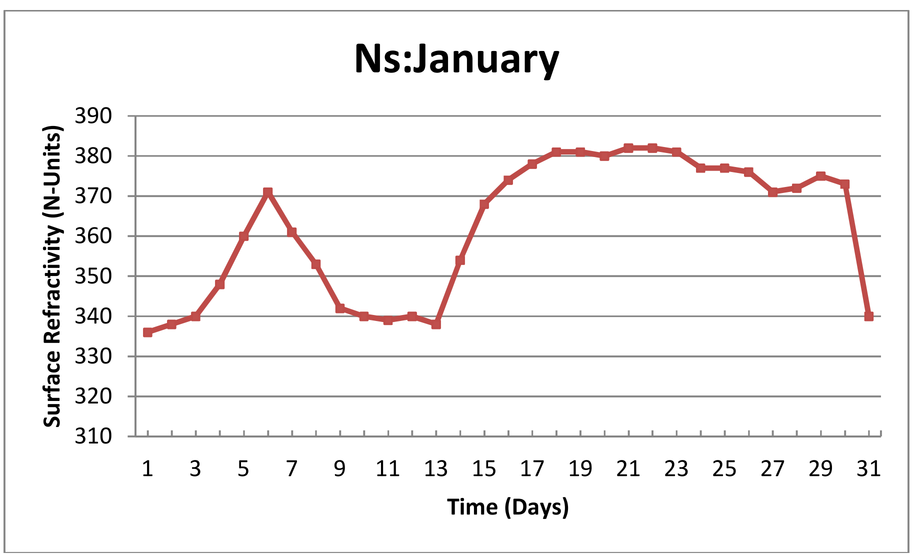

Fig. 1. Daily mean variations of surface refractivity over Awka for the month of January in dry season

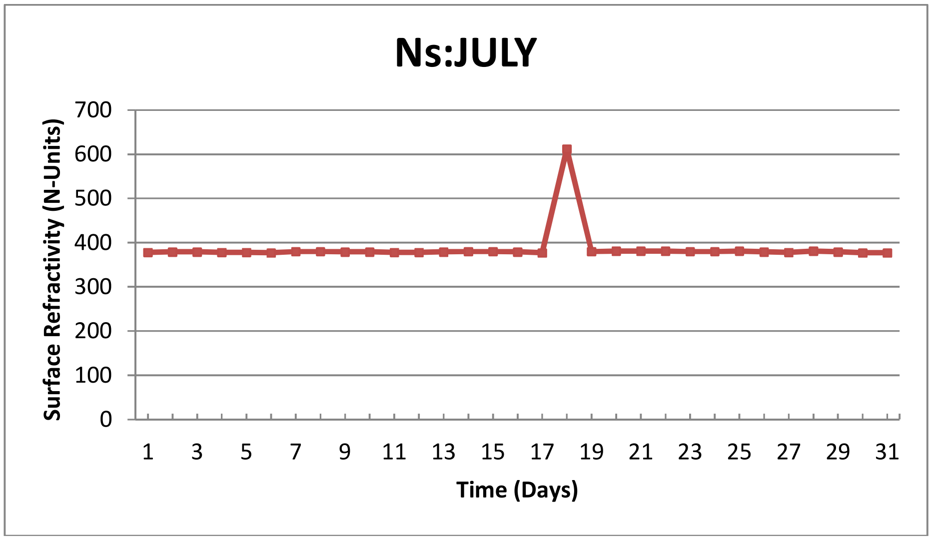

Fig. 2. Daily mean variations of surface refractivity over Awka for the month of July in wet season

through 11th and 13th day. The value rises again gradually until it reaches the value of 381 N-units on the 18th day. There is a steady variation of refractivity values between about the 20th and 29th day before it finally drops abruptly to 340 N-units on the 31st day due to high solar insolation and reduced humid content in the atmosphere during this time.

Fig. 2 shows an abrupt rise of surface refractivity with the highest value among other months of 612 N-units which takes place on the 18th day of the Month. There is observed stable high refractivity values throughout the month. July is a typical wet season in Awka and as such is expected high surface refractivity values.

Fig. 3 shows mean diurnal surface refractivity for both dry and rainy season months. The dry season months are November, December, January, February and March while the rainy season months are April, May, June, July, August, September and October. The rainy season months have higher refractivity values from the 1st day of about 379 N-units to the 16th day of about 378 N-units. The dry season months have lower refractivity values from the 1st day of about 331 N-units to the 16th day of about 377 N-units. The value of refractivity for dry season becomes higher than wet season on the 23rd day of about 399 N-units. This is due to high moisture content in the atmosphere during the strong cold Harmattan season on that day. The values of refractivity for rainy season are fairly stable while that of dry season have higher variability. The entire plot in Fig. 3 shows that wet season months have higher surface refractivity values and less variability while the dry season months have low surface refractivity and —higher variability. This corresponds to the observations of Oyedum and Gambo [9] that radio signal at VHF and UHF propagates higher during the rainy season than dry season due to high surface refractivity and fairly stable values.

In Fig. 4 it is observed that in Awka surface refractivity has the lowest value in January with the refractivity value of 362 N-units. This is attributed to high insolation and low moisture content in the atmosphere. There is gradual increase through the month of April when the moisture content of the atmosphere is high until it gets to the peak value. The mean maximum surface refractivity is 387 N-units which takes place in the month of July. Plot of fig. 4 also shows that the highest surface refractivity values takes place in wet season months (April to October) while the least surface refractivity values occur in dry season months (November to March). The higher surface refractivity in wet seasons is as a result of high relative humidity which is under the influence of moisture laden tropical maritime air from the continuous migration of the inter-tropical discontinuity (ITD) with the sun. The drop in refractivity values in dry months is as a result of dry and dust-laden wind which becomes dominant in the season.

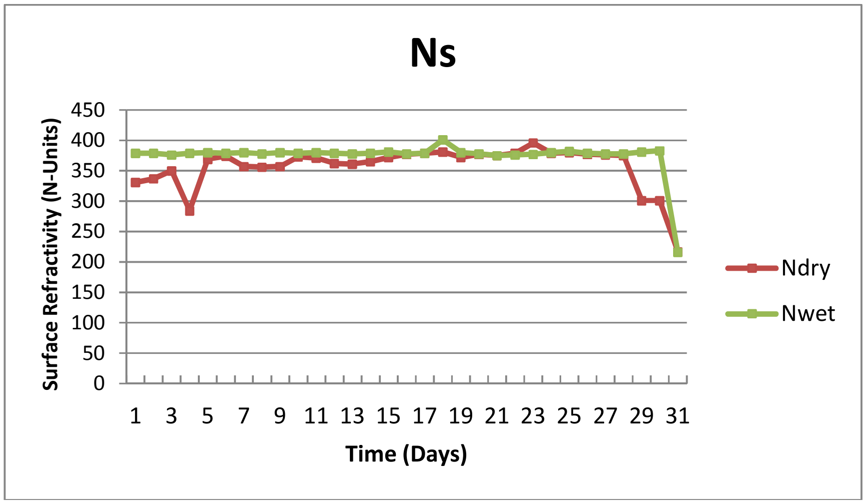

Fig. 3. Mean daily variations of surface refractivity for both dry and rainy season months

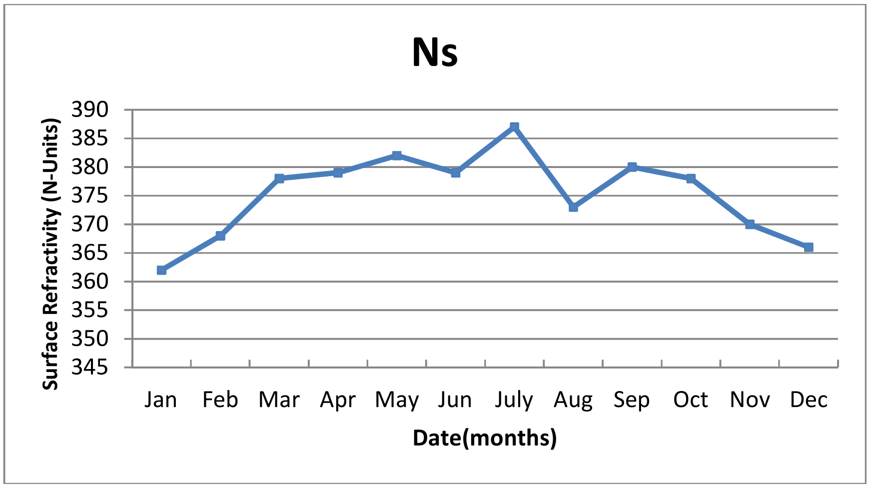

Fig. 4. Mean monthly variations of surface refractivity in Awka

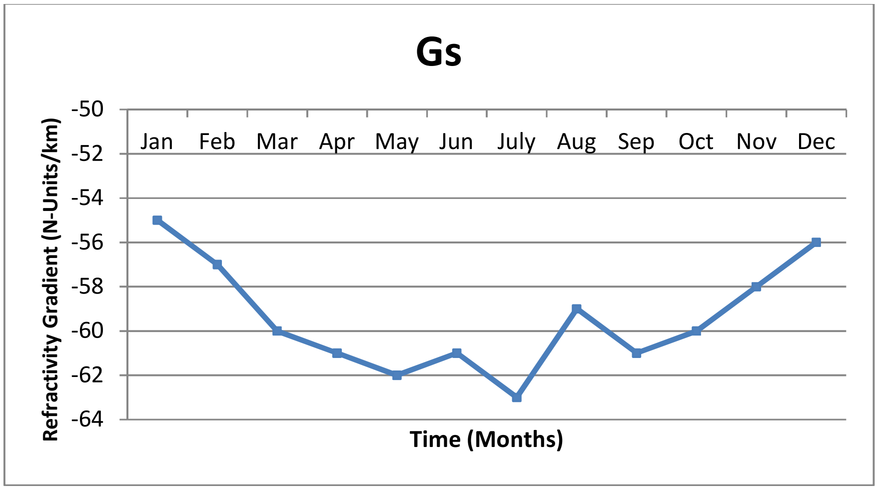

Fig. 5. Mean surface refractivity gradient over Awka for the years 2013 and 2014

Fig. 5 shows mean Radio Refractivity Gradient over Awka for the years 2013 and 2014. The average monthly refractivity gradient dN/dh from 2013 to 2014 over Awka was calculated and found to vary from -55 N-units/km to -60 N-units/km for the dry season periods and -60 N-units/km to -63 N-units/km for the wet season periods. The figure also shows that the monthly variations of refractivity gradient give large negative values in January corresponding to the period of intense Harmattan observed around Awka which is often characterised by very cool nights and morning times and very dry day time. The average value of refractivity gradient for years 2013 and 2014 is -59 N-units/km. From the average value 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 month of July in Awka for the two-year period, with mean refractivity gradient of -63 N-units/km. This shows that the more super-refractive the propagation condition, the greater the strength of signals and more importance it becomes to radio engineers in improving VHF/UHF terrestrial links.

5. CONCLUSIONS

The analysis of this work has shown that the surface refractivity for the two-year period over Awka showed seasonal variations with high values in the rainy season and low values in the dry season. The dry season was highly variable unlike the wet season refractivity which had small variability. For radio wave propagation in Awka and environs the propagation condition could mostly be super – refractive. But the month of January had the highest value of refractivity gradient while the least occurred in July.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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