Global Journal of Computer Science and Technology: G Interdisciplinary
Volume 20 Issue 2 Version 1.0 Year 2020
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals
Online ISSN: 0975-4172 & Print ISSN: 0975-4350

Variation of Microwave Radio Refractivity Profiles with Temperature over Akure, Nigeria

By Moses Ajewole, Adekunle Adediji, Joseph Ojo, Sunday Falodun, Kayode Adedayo, Theophilus Ewetumo, Ayodeji Ashidi, Samuel Adebusola, Kehinde Ogunjobi, Ayodeji Oluleye, Joseph Dada & Olalekan Ojo

Federal University of Technology

Abstract- A Preliminary result of the measurement of radio meteorological parameters for the profiling of radio refractivity over Akure, Nigeria, is presented. One year (January-December 2018) data of temperature, pressure, and relative humidity were collected for ground surface and heights of 50, 100, 150, and 200 m respectively from the ongoing measurement of the parameters by Communication Physics Research Group of the Federal University of Technology, Akure, Nigeria. From the data collected, radio refractivity, N were computed, and correlation of N with temperature was evaluated. Results showed that the mean value of surface refractivity obtained during this period of study is 365 N-units while that at the elevated altitudes are: 362, 359, 357, and 354 N-units respectively. It was also deduced that radio refractivity decrease with an increase in height, and its values were generally higher during the rainy season (April - October) than in the dry season months (November -March). Correlation between N and temperature was high during the wet season and low during the dry season.

Keywords: correlation, microwaves, radio refractivity, radiowaves, temperature.

GJCST-G Classification: I.4.1

VARIATIONOFMICROWAVERADIOREFRACTIVITYPROFILESWITHTEMPERATUREOVERAKURENIGERIA

Strictly as per the compliance and regulations of:

Variation of Microwave Radio Refractivity Profiles with Temperature over Akure, Nigeria

Moses Ajewole α, Adekunle Adediji σ, Joseph Ojo ρ, Sunday Falodun Ѡ, Kayode Adedayo ¥, Theophilus Ewetumo §, Ayodeji Ashidi χ *, Samuel Adebusola ν, Kehinde Ogunjobi ϴ, Ayodeji Oluleye ζ, Joseph Dada £ & Olalekan Ojo €

Abstract- A Preliminary result of the measurement of radio meteorological parameters for the profiling of radio refractivity over Akure, Nigeria, is presented. One year (January-December 2018) data of temperature, pressure, and relative humidity were collected for ground surface and heights of 50, 100, 150, and 200 m respectively from the ongoing measurement of the parameters by Communication Physics Research Group of the Federal University of Technology, Akure, Nigeria. From the data collected, radio refractivity, N were computed, and correlation of N with temperature was evaluated. Results showed that the mean value of surface refractivity obtained during this period of study is 365 N-units while that at the elevated altitudes are: 362, 359, 357, and 354 N-units respectively. It was also deduced that radio refractivity decrease with an increase in height, and its values were generally higher during the rainy season (April - October) than in the dry season months (November -March). Correlation between N and temperature was high during the wet season and low during the dry season. The results implied a strong probability of reduced radio horizon distance during the wet season and increased radio horizon distance during the dry season in this geographic region of the globe.

Keywords: correlation, microwaves, radio refractivity, radiowaves, temperature.

I. Introduction

The determination of microwave propagation conditions in the troposphere is pertinent for assessing the performance of both radio communications and radar systems. If radio waves (including radar) are propagated in free space, the path followed by the waves is a straight line. However, as these waves travel through the earth's atmosphere, they encounter variations in the atmospheric refractive index along its trajectory, which then caused the ray path to become curved. This curvature is a result of perturbations in meteorological parameters such as humidity and temperature in the troposphere, which in turn lead to a change in the density of air.

As the conditions of radio propagation in the atmosphere vary from the standard case, anomalous radio wave propagation is observed. Such anomalies are caused by abnormal variations of some meteorological conditions (inversion of temperature, high evaporation and humidity, the passing of the cold air over the warm surface and, conversely) [1]-[2]. Furthermore, air temperature, pressure, and humidity depend on the height at a point above the ground surface and, small changes in any of these variables can have a significant influence on radio waves because radio signals can be refracted over the whole signal path [3]. In a well-mixed atmosphere, pressure, temperature, and humidity decrease exponentially as a function of height [4]. Most of the recent works done on this subject in Nigeria are based on satellite and extrapolated data from radiosonde measurements. Examples include [5]-[9] and so on. The information on radiosonde measurements lacks the spatial and temporal resolutions, which are necessary for the determination of small-scale variations, particularly in the lower atmosphere [3]. Moreover, accurate detection of weather parameter variations at different strata within the lowest layer of the atmosphere demands a level of precision that is often beyond the scope of radiosonde measurement [10].

In this study, radio refractivity values are computed for ground surface and elevated heights of 50, 100, 150, and 200 m, respectively, through in-situ measurement of some atmospheric variables (temperature, pressure, humidity, rain-rate, dew-point and so on). The vertical correlation between temperature and radio refractivity are thus determined.

II. Radio Propagation and Refractivity

The earth's atmosphere is characterized by several different parameters: temperature, pressure, relative humidity, wind, precipitations, solar radiation, and so on. These parameters exhibit variations based on geographic position, season, time of the day, and solar cycle [11]. The degree of accuracy of their measurements is usually a function of the care exercised by the experimenter/observer and the sensitivity of the equipment used in the observation [12]. Radio propagation relates to the mechanism of transmitting radio waves from one point to another on the earth or into various parts of the atmosphere without

Author α σ ρ Ѡ ¥ § χ ν: Department of Physics, Federal University of Technology, Akure. Nigeria. e-mail: agashidi@futa.edu.ng
Author ϴ ζ: Department of Meteorology and Climate Science, Federal University of Technology, Akure, Nigeria.
Author £ €: Department of Physical and Chemical Sciences, Elizade University, Ilara-Mokin, Ondo State, Nigeria.

the use of transmission lines. As a form of electromagnetic waves like light waves, radio waves are affected by absorption, scattering, reflection, refraction, diffraction, polarization, daily changes of water vapor in the troposphere and ionization in the upper part of the atmosphere due to the sun and so on [13]. The effect of varying conditions of the atmosphere on radio propagation has many practical implications such as; choosing frequencies for shortwave broadcast, designing of reliable mobile telephone systems, radio navigation, operation of radar systems, and so on. Different radio waves are propagated via different mechanisms depending on their respective frequencies; hence, at extremely low and very low frequencies (ELF and VLF), the wavelength is much larger than the separation between the earth's surface and the D layer of the ionosphere so that electromagnetic waves may propagate in this region as a waveguide [14]. Indeed, for frequencies below 200 kHz, the wave propagates as a single wave mode with a horizontal magnetic and vertical electric field [15].

All electromagnetic waves are transmitted at the same speed in free space, irrespective of the frequency. The velocity of light in a vacuum, which is often referred to as the speed of light given as 3×10^8 m/s, is used as a reference. The velocity of any propagating wave is dependent on the medium in which it is traveling.

The refractive index of the troposphere is consequential in predicting the performance of terrestrial radio links. Its variations in the atmosphere affect radio frequencies above 30 MHz, although these effects become significant only at frequencies exceeding about 100 MHz, especially in the lower atmosphere [16]. The radio refractive index, n of the troposphere, deviates slightly from unity due to the polarizability of the constituent molecules by the incident electromagnetic field and the quantum mechanical resonance at some unique frequency bands. While molecular polarizability is independent of frequency up to millimeter waves, molecular resonance is frequency-dependent, and n tends to be dispersive above ~ 50 GHz [17].

The radio refractive index of a medium is defined as the ratio of the velocity of propagation of a radio wave in free space to the velocity in the medium. At standard atmospheric conditions near the earth's surface, the radio refractive index (n) has a value of approximately 1.0003. However, in the design of radio systems, the use of a scaled-up unit is more desirable. This scaled-up unit is called the radio refractivity (N), and is related to n as [18]:

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

where N is a dimensionless quantity expressed in N-units.

In terms of measured meteorological quantities, N can be expressed as [19], [18]:

$$N = N_{dry} + N_{wet} = 77.6\frac{p}{T} + 3.73\times10^{5}\frac{e}{T^{2}} \tag{2}$$

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

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

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

$$N_{wet} = 3.732\times10^{5}\frac{e}{T^{2}} \tag{4}$$

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

The dry term contributes about 70% to the value of N, and the wet term is responsible for the greater part of the variation in N at a given location in the atmosphere. Equation (2) can be utilized for radio frequencies up to 100 GHz. The error associated with the use of this expression is less than 0.5% [18].

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

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

with:

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

and;

$$EF_{water} = 1 + 10^{-4}\left[7.2 + P\times(0.00320 + 5.9\times10^{-7}\times t^{2})\right] \tag{7a}$$

$$EF_{ice} = 1 + 10^{-4}\left[2.2 + P\times(0.00382 + 6.4\times10^{-7}\times t^{2})\right] \tag{7b}$$

where t is temperature (°C), P is pressure (hPa), H is relative humidity (%) and e_s is saturation vapour pressure (hPa) at the temperature t (°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° and +50°) and for ice; a = 6.1115, b = 23.036, c = 279.82 and d = 333.7 (valid between -80° and 0°) (ITU-R 2012).

III. Instrumentation, Measurement Techniques and Scope of Data

Nigeria is located at 7.62°N, 6.97°E, in West Africa. It has two main distinct seasons: Wet and Dry seasons. The dry season extends from November to March, while the wet/rainy season runs from April to October. The change of the season occurs in association with the meridional movement of the Inter-Tropical discontinuity (ITD), which demarcates the warm and cold (maritime) South-Westerly trade winds from the warm and dry (continental) North eastern trade winds at the surface [20]. The movement of the ITD is very irregular, varying per month according to the seasons from latitude 2.0° N to 5.0° N. The diurnal temperature range is about 12°C with the mean minimum of about 21°C during the day.

The measurement site of this research work is located at Iju in Akure North Local Government area of Ondo State, which is located in the Southwestern part of Nigeria. It is about 17 km by road away from the city of Akure, and about 25 km by road from the campus of the Federal University of Technology, Akure (FUTA), and about 11.5 km on a line of sight from Akure (Fig. 1). Its geographic coordinates are 7.15° N, 5.12° E [21]. This location is in the sub-humid tropical forest zone of West Africa. The site Iju was chosen because of the availability of the Nigerian Television Authority (NTA) mast, which is currently not in use for transmission purposes by the NTA due to their relocation to a new site. The height of the tower is 220 m. This high tower provides an excellent platform for the investigation of radio refractivity profile and its gradient in the lower layers of the troposphere in Akure since most service providers, radio and TV broadcasts, GSM service providers have their transmitting antennas on masts not higher than 200 m in this location.

The data of temperature, pressure, and relative humidity for the computation of refractivity used in this work was measured using the Davis 6162 Wireless Vantage Pro 2 weather instrument equipped with the integrated sensor suite (ISS), a solar panel (with an alternating battery source), and the wireless console for remote reception of signal from the ISS and provide user interface data display. The ISS collects outside weather data and sends the data to a Vantage Pro2 console. Both the wireless console and cable versions of the ISS are available, but the wireless versions are used in this study.

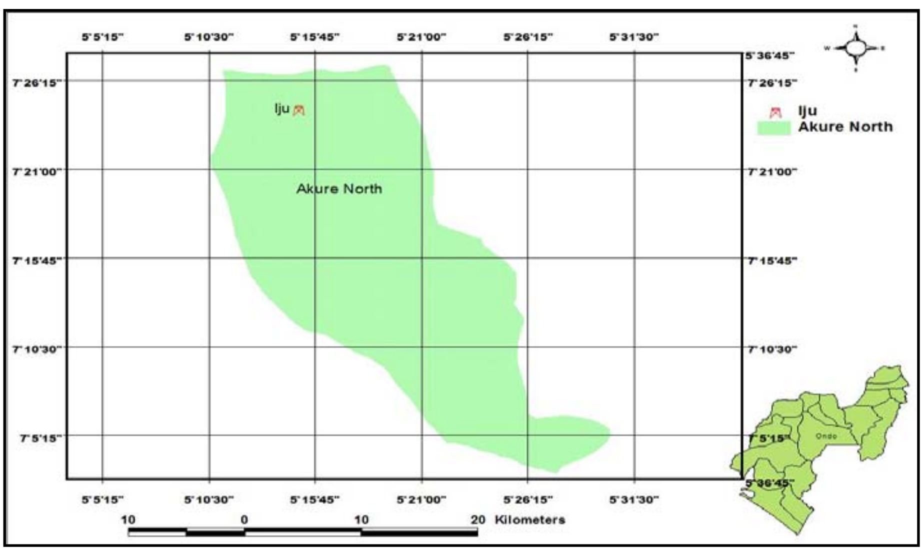


Figure 1: Map of the experimental site in Ondo State, Nigeria

The frequency of transmission of the ISS is 868.0 – 868.6 MHz. The ISS has error margins of ±0.5°C, ±0.5hpa, and ±2% for temperature, pressure, and relative humidity respectively [22] – [23]. The data from the ISS is then transmitted by radio to the console/receiver. The console has an LCD screen and keyboard, which provides easy access to the weather information. The large LCD shows current and past environmental conditions as well as a forecast of future conditions. The keyboard controls the console functions for viewing current and historical weather information, changing station types, selecting sensors, viewing/changing station settings, viewing graphs, and so on.

The fixed measuring method by a high tower is employed for the measurement with the ISS positioned at the ground level for measuring the surface weather parameters, temperature, atmospheric pressure, and relative humidity. The remaining four are stationed at heights of 50 m, 100 m, 150 m, and 200 m for continuous measurement of meteorological parameters while other auxiliary devices are on the ground. The data measured by the sensors are transmitted as signals to the receiver (console) by radio waves. The data are transmitted by wireless radio to the data logger attached to the console located on the ground from which the data are then copied to the computer.

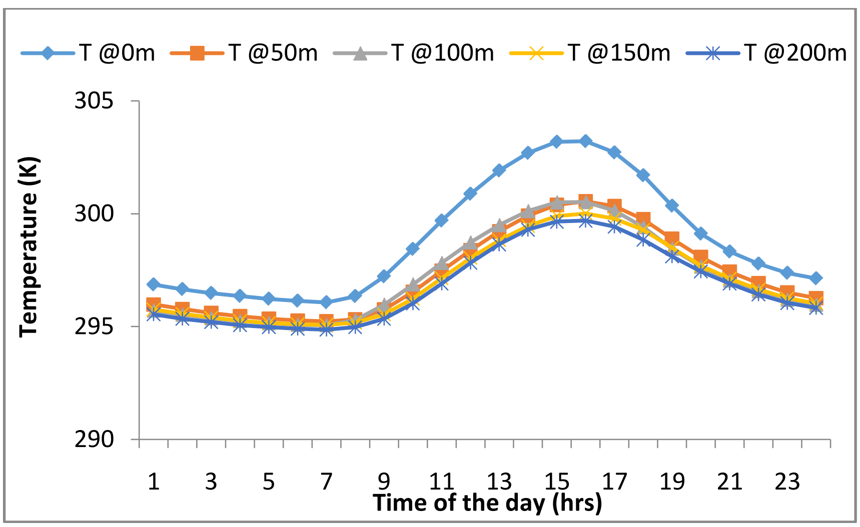
One year data of in-situ measurement were used for this work (January 2018-December 2018). The measurement of the air temperature, atmospheric pressure, and relative humidity was taken every 30 minutes of each day from 00:00 hour to 23:00 hours local time by the instrument. From the daily records of the data collected, the values of pressure in hPa, the temperature in 00°C and relative humidity in percentage were extracted.

Radio refractivity was then computed from the extracted data of temperature, pressure, and relative humidity using equations (2) to (7).

IV. Results and Discussion

a) Diurnal variation of the vertical distribution of temperature

The diurnal variation of temperature in Akure for both wet and dry seasons from the ground surface to 200 m altitude is shown in Figure 2 (a and b). From figure 2a, the temperature was lowest around 07:00 hr local time before it gradually rises to a maximum at about 16:00 hr local time across all levels. The highest value of temperature between 07:00 hr and 16:00 hr local time at all the levels occurred at the ground surface. The temperature profile shows that temperature decreases with height over Akure during the wet season. From figure 2b, the temperature was almost linear from 00:00 to 07:00 hr local time across all the heights. The temperature was also lowest at 06:00 hr local time between the ground surface and 200 m altitude. At the height interval 50-150 m, it was lowest around 07:00 hr local time. It reached its peak around 16:00 hr local time across all the heights. This pattern confirms the dependence of temperature on solar irradiance reaching the earth during the daytime in both seasons of the year.



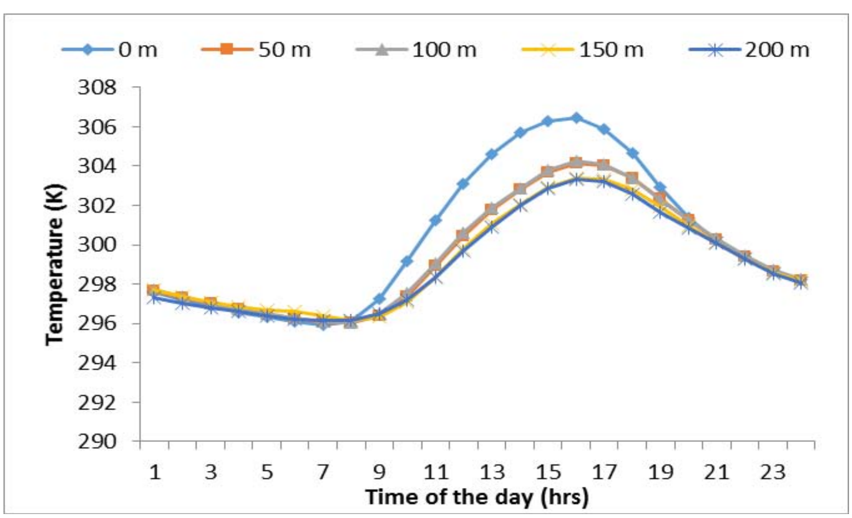
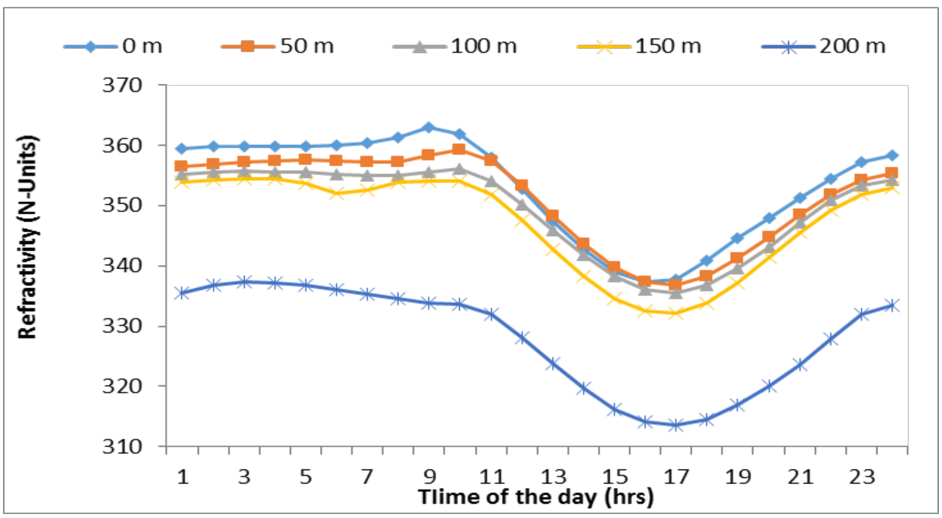


Figure 2: Diurnal variation of temperature at all levels for (a) wet months and (b) Dry months

b) Diurnal variation of the vertical distribution of radio refractivity

The diurnal variation of radio refractivity over Akure for the wet season months is shown in Figure 3a. It is deduced that refractivity values gradually drop till 05:00 hrs and later rise to a maximum of 377 N-units around 10:00 hr local time. The values decrease to a minimum of 372 N-units around 16:00 hrs, after that, increasing for the rest of the day at the ground surface. This type of variation is also observed at the elevated altitudes with different minimum and maximum values across the heights. At altitudes of 50 m, 100 m, 150 m, and 200 m, refractivity drop to a minimum of about 368, 365, 361, and 358 N-units respectively at 16:00 hr local time, as applicable to the ground surface. The maximum values of refractivity obtained around 10:00 hrs are 372, 369 N-units at 50 and 100 m, respectively, while at 150 and 200 m, refractivity is about 367, and 365 N-units around 09:00 hr local time respectively. The figure also shows that radio refractivity decreases with an increase in height over Akure. The diurnal variation of refractivity over Akure for the dry season at different heights is shown in Figure 3b. The radio refractivity at the surface shows a high value of 359 N-units to about 363 N-units during the early hours of the day and late in the evening. The N-values start reducing at 09:00 hr local time and reach a minimum of 337 N-units at 16:00 hr local time. Similar patterns were replicated at other levels except 200 m altitude, which has its maximum value of 337 at 02:00 hr local time and a minimum of 314 at 16:00 hr local time. At 50, 100, and 150 m altitudes, the maximum values of 359, 356, and 354 N-units respectively occurred at 09:00 hr local time while minimum values of 337, 335, and 332 N-units at 16:00 hr local time. This variation was due to the response of the earth to solar radiation, which causes the temperature to be high and humidity values to be lower during the day.



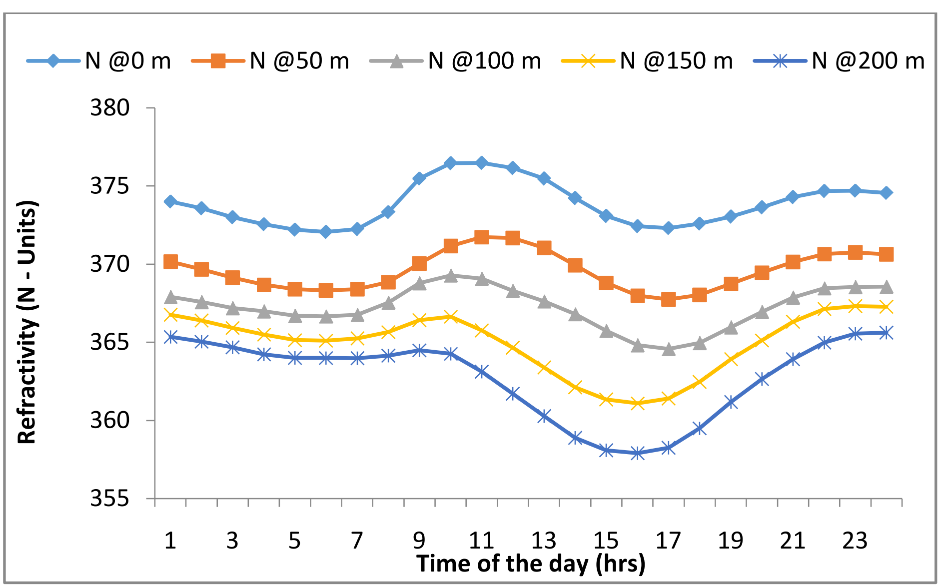


Figure 3: Diurnal variation of refractivity at all levels for (a) wet months and (b) Dry months

c) *Diurnal variation of refractivity with temperature for wet and dry seasons*

The diurnal variation of refractivity with temperature for dry season months is presented in Figure 4. It is observed that temperature varies in the opposite direction to refractivity at all levels. It could be noted that the decrease in refractivity from 09:00 hr local time to its lowest value at 16:00 hr local time is due to an increase in temperature, which starts at 07:00 hr local time and reaches its maximum value at about 15:00 hr local time. This same variation trend occurs at all levels except 200 m altitude.

The diurnal variation of refractivity with temperature for the wet season is shown in Figure 5. It can be seen from the figure that refractivity has two peaks while temperature has one during this period. The first peak of 377 N-units around 10:00 hr local time while the second peak of about 375 N-units at 22:00 hr local time occurred when the temperature at these times are 300 and 297 K respectively at the surface level. A Similar trend is also observed at other levels with different first and second peak values of refractivity. The observed pattern shows that wet term drives refractivity variation in dry season while the dry component drives refractivity variation over Akure in the rainy season.

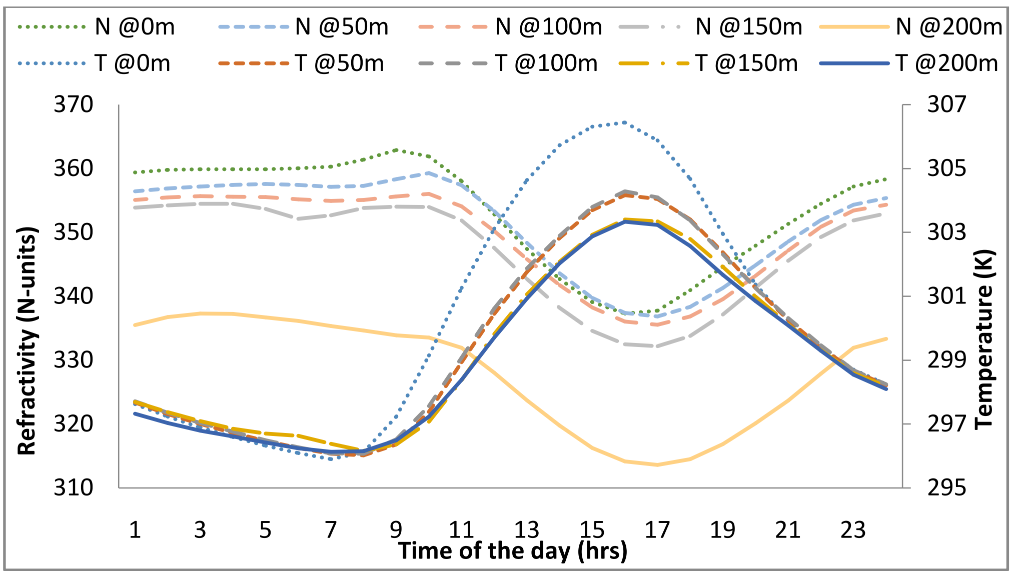


Figure 4: Diurnal variation of refractivity with temperature at all levels for dry months.

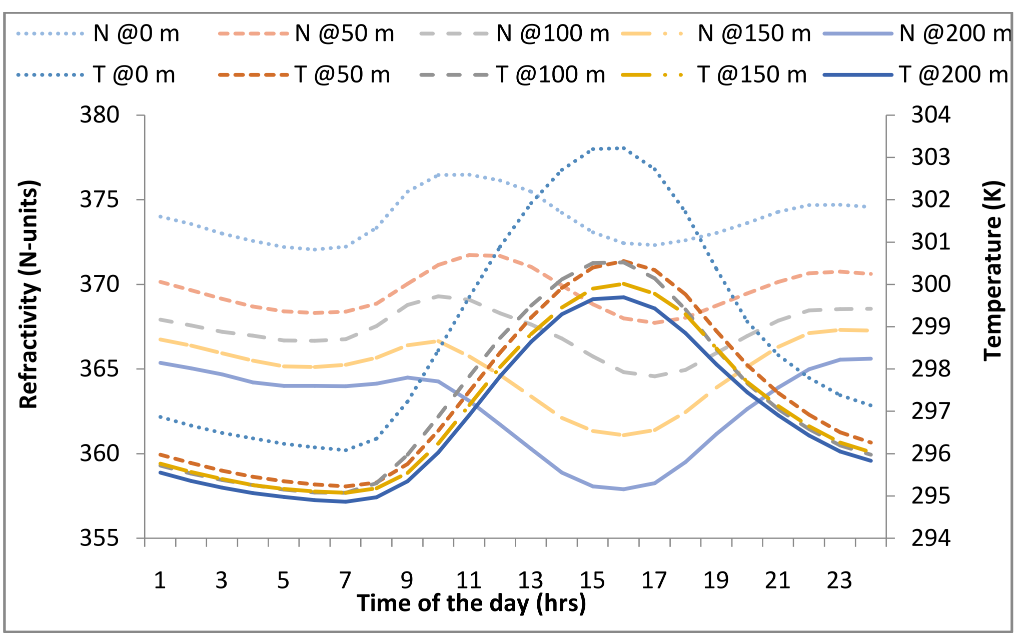


Figure 5: Diurnal variation of refractivity with temperature at all levels for wet months.

d) Seasonal variation of the vertical distribution of radio refractivity

The seasonal variation of radio refractivity from the surface to 200 m height is shown in Figure 6. It is observed that the rainy season months (April-October) have high refractivity values ranging from a total average of 371 - 376 N-units with the highest value occurring in September and October at the ground surface. At an altitude of 50 m, the values of refractivity range from 368 - 371 N-units with the highest and lowest values of refractivity occurring in May and August, respectively. At the altitude of 100 m, the refractivity values range from 362-369 N-units with the highest and lowest values occurring in May and August. At 150 and 200 m altitudes, the values of refractivity respectively range from 363-367 N-units and 359-365 N-units, respectively. Their highest and lowest values also occurred in May and August. These high values are associated with extensive cloud cover and saturation of the atmosphere with a large amount of water vapor during this period in Akure. The low amount of refractivity recorded in the month of August can be attributed to the occurrence of a slight drought called 'August-break' in the rainy season in this rain forest zone of Nigeria. The break usually lasts for about 2–3 weeks, during which water vapor pressure at the surface is minimum. Its occurrence is in association with the ITD reaching its northern-most position and consequently retreating southward, and this gradually leads to the end of the rainy season in October.

On the other hand, the dry season months (November-March) recorded lower radio refractivity values than the rainy season months. These low refractivity values vary from 332-368 N-units with a span of 36 N-units at the ground surface for the five years. At the altitude, 50 m, and100 m, the values vary from 330-365 N-units with a range of 35 N-units and 325-362 N-units with a range of 37 N-units respectively, while that of 150 and 200 m are 326-360 N-units with a range of 35 N-units and 318-360 N-units with a range of 42 N-units. A large seasonal variation of refractivity is displayed in the dry season months than the rainy season. The dry months reflect the strong influence of dry continental air mass prevalent during this period. The variation of mean values of radio refractivity with height, as shown in Figure 7 reveals that refractivity decreases with an increase in height.

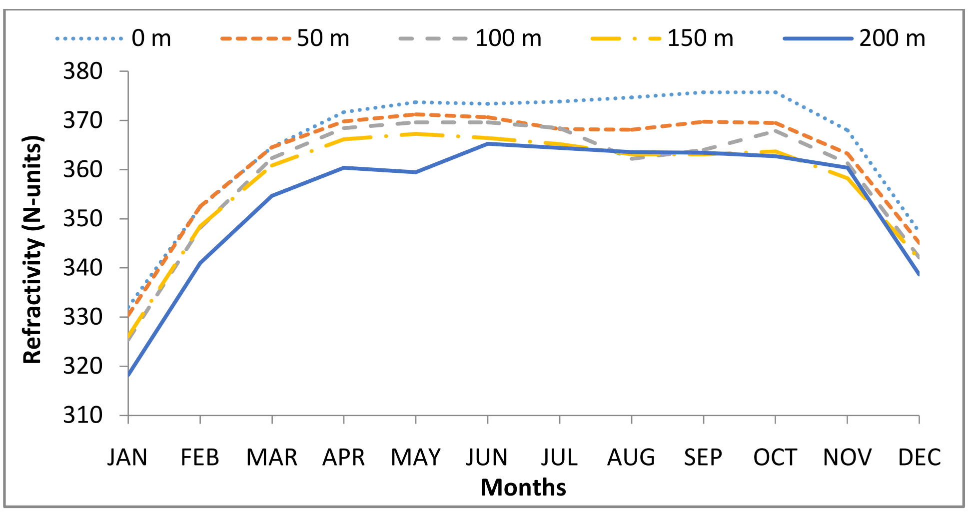


Figure 6: Seasonal variation of refractivity at all levels for the period of study

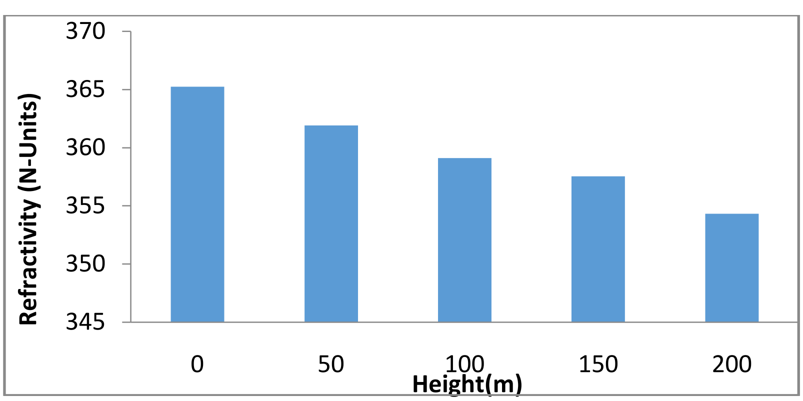


Figure 7: Variation of refractivity with height

e) Vertical profile of the seasonal variation of radio refractivity with temperature

The seasonal variation of radio refractivity with temperature from the ground surface to 200 m height is shown in Figure 8. It is observed that temperature has high values during the dry months (Nov-Mar) while radio refractivity has low values during this period. As the temperature begins to increase from November to March, refractivity starts to reduce during this period. The highest values of refractivity and temperature in the dry season occurred in March and February, while their lowest values occurred in January and November at all heights during this period.

The wet season months (April-Oct) have high values in radio refractivity with low values in temperature during this period. The highest and lowest values of temperature during the wet months occurred in April and August respectively at all heights considered, while that of refractivity was recorded in May and August, except ground surface which has the highest and lowest values in September and June.

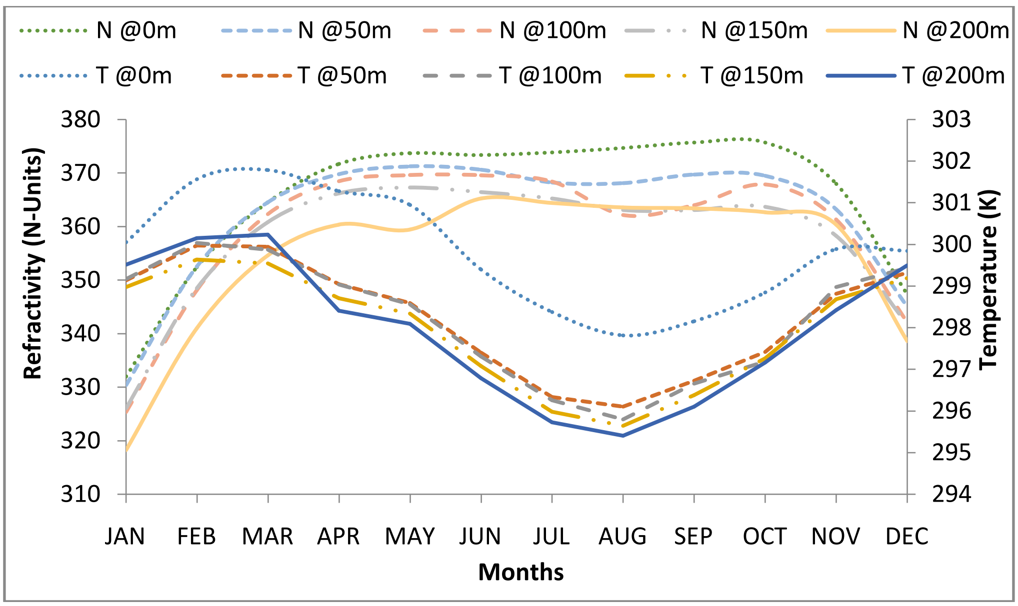


Figure 8: Seasonal variation of refractivity with temperature at all levels for the period of study.

f) Seasonal correlation of refractivity with temperature

Correlation is a statistical tool that provides information on the relationship between any two sets of variables with the view to determining the dependence of one on the other. Dependence refers to any statistical relationship between two random variables or two sets of data. There are a good number of correlation coefficients, usually represented by ρ or r, for determining the level of mutual dependence of the variables being investigated. The Pearson correlation coefficient algorithm is one of the most widely deployed for investigating linear relationships between two variables [24].

From the result obtained for mean monthly temperature and radio refractivity, seasonal correlation coefficient (r), and the coefficient of determination for the wet months (April-October) and dry season months (Nov-March) in this study are determined. These correlation coefficients are presented in Table 1. Radio refractivity and temperature are negatively correlated with a correlation coefficient of -0.75 and a coefficient of determination of 0.56 at the ground surface. These values imply that 56% of radio refractivity values can be accounted for by temperature at the surface during the rainy season months. The correlation analysis at 50-100 m shows that refractivity and temperature are positively correlated with a decrease in both correlation coefficient and coefficient of determination compared to surface level. The high correlation coefficient at 200 m level shows that temperature contributes 63% to radio refractivity during this period.

Contrary to this, the correlation analysis between radio refractivity and temperature for dry season months shows that the correlation coefficient and coefficient of determination have low values ranging from 0.19-0.33 and 0.04-0.11, respectively. The coefficients mean that the highest radio refractivity values that can be accounted for by temperature during the dry season are 11%, an indication that temperature has little contribution to refractivity variation during the dry season months, as observed in this study.

Table 1: Seasonal Correlation of Refractivity with Temperature

	Wet months		Dry months	
Height (m)	Correlation coefficient r	Coefficient of determination r^2	Correlation coefficient r	Coefficient of determination r^2
0	-0.75	0.56	0.33	0.11
50	0.73	0.53	0.24	0.06
100	0.66	0.43	0.23	0.05
150	0.70	0.50	0.19	0.04
200	-0.79	0.63	-0.25	0.06

V. Conclusion

The radio refractivity-temperature profile correlation over Akure, South-Western, Nigeria, has been investigated. The following results were deduced from this work:

1. The diurnal variation of refractivity with temperature in dry season exhibits one cycle for 24- hour period. During the rainy season, radio refractivity exhibits two cycles, while temperature has one cycle during this period.
2. The mean value of surface radio refractivity obtained during this period is 365 N-units. At the other levels (50, 100, 150, and 200 m), the values are 362, 359, 357, and 354 N-units, respectively; an indication that radio refractivity decreases with an increase in height. Radio refractivity is generally high during the rainy season (April - October) than in the dry season months (November - March).
3. Seasonal correlation analysis between refractivity and temperature shows that there is a high correlation coefficient for the wet months and low correlation coefficient for the dry months in this study.

Acknowledgments

The authors' profound gratitude are hereby expressed to Tertiary Education Trust Fund (TETFund) for Institution-Based Research (IBR) Grant for sponsoring this research. Also, we are grateful to the Centre for Basic Space Science, University of Nigeria Nsukka, Nigeria, for donating two sets of the Integrated Sensor Suite (ISS) and research collaborations. Lastly, The Nigeria Television Authority (NTA) is appreciated for the release of its facilities.

References Références Referencias

1. Valma, E., Tamošiūnaitė M., Tamošiūnas S., Tamošiūnienė M., and Žilinskas M. (2010). "Determination of Radio Refractive Index using Meteorological Data" Electronics and Electrical Engineering. – Kaunas: Technologija, No. 10 (106). – P. 125–128.
2. Valma, E., Tamosiunaite M., Tamosiunas S., Tamosiuniene M., and Zilinskas M. (2011) "Variation of radio refractivity with height above ground". Electronics and Electrical Engineering, Telecommunication Engineering No 5, pp. 23-26.
3. Lowry, Anthony R., Chris Rocken and Sergey V. Sokolovskiy "Vertical profiling of atmospheric refractivity from ground-based GPS", Radio Science, vol. 37, No 3, pp. 13-1-13-10, 2002.
4. Falodun, S. E., and Ajewole, M. O. (2006) "Radio refractivity index in the lowest 100m layer of the tropospheric in Akure, South western" .J. of Atm and Solar-terrestrial Physics. Vol. 68, pp. 236-243.
5. Falodun, S.E and Kolawole, L.B (2000): Studies of super-refractivity and ducting of radiowaves in Nigeria. Nigeria journal of Pure and Applied Physics, vol. 1, 5-10.
6. Willoughby, A. A., Aro T. O., and Owolabi I. E., (2002) Seasonal variations of radio refractivity gradients in Nigeria Journal of Atmospheric and Solar– Terrestrial Physics. Vol., 64 pp. 417–425
7. Adeyemi, B and Ewetumo, T (2006): Intra-layer (low-level/upper level) refractivity relations over Lagos and Kano. Global journal of pure and applied sciences, vol. 12, No 3. 403-408
8. Adeyemi, B. and Emmanuel I. (2011) "Monitoring tropospheric radio refractivity over Nigeria using CM-SAF data derived from NOAA-15, 16 and 18 Satellites" Indian Journal of Radio and Space Physics, Vol.40, pp.301-310.
9. I. Emmanuel, B. Adeyemi, E.O. Ogolo, A.T. Adediji (2017) "Characteristics of the anomalous refractive conditions in Nigeria". Journal of Atmospheric and Solar-Terrestrial Physics 164, 215–221.
10. Hajj, G.A, Kursinski, E.R, Romans, L.J, Bertiger, W.I and Leroy, S.S (2002): A technical description of atmospheric sounding by GPS occultation. Journal of Atmospheric and Solar –Terrestrial Physics. Vol. 64, 451-469.
11. Umoh, T.U., 2000. Rainfall characteristics and agricultural planning in Northern Nigeria. Niger. Teach. Geogr. J. 2, 48–54.
12. Adedokun, J.A. (1978) "West Africa Precipitation and dominant atmospheric mechanisms, Arch. Meteorol Geophys Bioclimatol, Vol. 27,pp 289-310.
13. Bech, J, Codina, B, Lorente, J and Bebbington, D. (2002) "Monthly and daily variations of radar anomalous propagation conditions: How ''normal'' is normal propagation?" Proceedings of ERAD.

14. Gao, J., Brewster K., and Xue, M. (2007) "Variation of radio refractivity with respect to moisture and temperature and influence on radar ray path". Advances in Atmospheric Science, Vol. 25 (6), pp. 1098-1106.
15. Hall M.P.M and Barclay L.W (1989) "Radio wave propagation". Peter Peregrinus Ltd, UK.
16. Mentes, S., Kaymaz, Z., 2007. Investigation of surface duct conditions over Istanbul, Turkey. Journal of Applied Meteorology and Climatology 46, 318–333.
17. Ali, S., Malik, S. A., Alimgeer, K. S., Khan, S. A. and Ali, R. L. (2012). "Statistical Estimation of Tropospheric Radio Refractivity Derived from 10 years Meteorological Data". *Journal of Atmospheric and Solar – Terrestrial Physics.* Vol. 77, pp 96 – 103.
18. ITU-R (2012): The Radio Refractive Index: Its formula and refractivity data pp.835
19. Grabner, M and Kvicera, V (2003): Clear-air propagation modelling using parabolic equation method. Radio Engineering, vol 12, No 4, 50-54.
20. Arya, S.P. (1988) An introduction to micrometeorology, Academic Press, conangla, L 2000
21. Adediji, A.T., Ajewole, M.O., Falodun S.E., and Oladosu, O.R., (2007) "Radio Refractivity Measurement at 150m Altitude on TV Tower in Akure, South-West Nigeria" Journal of Engineering and Applied Sciences 2(8), Medwell Journals, pp.1308-1313
22. 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, pp. 157-168.
23. A.T. Adediji and M.O. Ajewole (2010) "Microwave anomalous propagation (AP) measurement over Akure South-Western Nigeria". Journal of Atmospheric and Solar-Terrestrial Physics 72 550–555.
24. Taylor R. (2008) "Interpretation of the Correlation Coefficient: A Basic Review. JDMS 1: 35-39.