Original research article

Diurnal, Seasonal and Annual Variation of Microwave Radio Refractivity Gradient over Akure, South West Nigeria

Abstract

In this study, four years in-situ measurements of atmospheric parameters (pressure, temperature and relative humidity) were carried out. The measurement was by placing an automatic weather station at five different heights: ground surface, 50, 100, 150 and 200 m respectively on a 220 m Nigeria Television Authority TV tower in Akure, South Western Nigeria. The four years Data collected (January 2007 to December 2009 and January to December 2011) were used to compute radio refractivity and its gradient. The local effect of a location/ region cannot but looked into when designing effective radio link, hence the diurnal, seasonal and annual variations of the radio refractivity gradient were studied. Results showed that refractivity gradient steadily increases in the hour of 8:30 and 9:30 to 18:00 during dry season throughout the years investigated, and decreases two hours in the rainy season than the dry season. The record shows that at 50 m altitude, the maximum and minimum values are 158 N-unit/km around 14:30 and - 286 N-unit/km around 13:30 to 14:00 hrs, LT during the dry and rainy season respectively. Seasonally, refractivity gradient is steeper with greater variability in the dry season months than in the wet season months.

Keywords: Microwave; Radio; Refractivity; Refractivity gradient; Temperature; Relative humidity

1 Introduction

Communication as a means of passing information from one point (transmitter) to another (receiver) has various barriers with respect to the content and the medium through which the information is begin carried. The propagation of the waves for the transmission of the information is essential for the development of communication services. Waves propagated from a transmitter to a distant receiving antenna experience diffraction, scattering and reflection as a factor that affect the transmitted signal through the propagated medium [Tanko *et al.* (2018)]. The propagation environment is the geographical area where the wave spreads between the transmitter and receiver. The physical parameters of the area such as pressure, temperature, humidity and so on defined the medium of the propagation [Sizun (2005)]. Methods for measuring these parameters are relatively standard, and degree of accuracy of their measurements is usually a function of care exercised by the observer and the sensitivity of the equipment used [Adedokun (1978)]. Results created by these parameters determine the value of the refractive index and its gradient.

The absolute refractive index of a medium is the ratio of the velocity of propagation of radio waves in a vacuum to its velocity in the specified medium. However, how far a radio signal will travel within the visible/radio horizon is determined by the distribution of radio refractivity. The difference in temperature, humidity and pressure that occurred at various heights and in different air masses leads to the principal cause of refraction in the atmosphere. The large-scale variation of refractive index with height and the extent to which it changes with time is one of the major factors that influence radio wave propagation [Hall (1979)]. The path followed by radio waves during propagation in the atmosphere depends upon the gradient of refractive index along that path. The refractive index gradient in the lower path of the atmospheric area is of much importance because it helps in characterizing the propagation conditions of the atmosphere [Bean and Dutton (1966)].

The troposphere is the lowest layer of the atmosphere extending about 10 km above the earth's surface. It is a turbulent layer that generates weather, and its temperature decreases with altitude. The variations in the vertical profiles of the refractive index and its gradients are responsible for the changes in the trajectory of radio waves in the troposphere. It was noted that occurrence of anomalous propagation is due to deviation of the vertical gradient of refractive index when atmospheric temperature and humidity distributions deviate from the normal/standard radio atmospheric conditions [Battan (1973)and Žilinskas *et al.* (2011)]. The meteorological parameter (atmospheric temperature, humidity, and pressure) experience diurnal variations due to the disparities of weather phenomena, especially in the lower and middle troposphere [Tjasyono and Djakawinata (1999)]. These effects introduce a diurnal variation of the refractive index gradient, whereas the diurnal variation shows more of the local effect on the propagation of radio waves.

This study presents the result of the diurnal, seasonal and annual variation of radio refractivity gradient from an in-situ measurement of meteorological parameters (atmospheric temperature, humidity, and pressure).The measurement was from five different altitudes beginning from the ground surface to 200 m with 50 m intervals in Akure for a period of four years (January 2007 to December 2009 and year 2011).

1.1 Radio Refractivity and Refractivity Gradient

The refractive index n, of air, is very close to unity (about1.0003) and is measured by a quantity called the **radio refractivity N**. Refractivity is the function of air pressure, temperature, and humidity and is usually considered with certain assumptions, as [Gao *et al.* (2007)]:

$$n = 1 + N \times 10^{-6} \quad (1.1)$$

Based on ITU recommendation [ITU-R (2003)], N is interrelated as:

$$N = 77.6\ P/T + 3.73 \times 10^5\ e/T^2 \tag{1.2}$$

where *P* is atmospheric pressure (hPa), *T* is the temperature (K), and *e* is water vapor pressure (hPa).
N is a dimensionless quantity. Hence, N is expressed, by convention, in N units. The expression (1.2) may be used to determine refractivity for all radio frequencies up to 100 GHz [Freeman (2007)], and the error alongside with this expression is less than 0.5% [ITU-R (2003)]. The relationship between relative humidity and the saturated water vapor pressure from which the water vapor pressure e, can be calculated, is given as:

$$e = H \times \frac{6.1121\ exp(\frac{17.502\ t}{t+240.97})}{100} \tag{1.3}$$

where H is relative humidity (%), t is a temperature in degree Celsius (°C), and e is water vapor pressure (hPa) at temperature t (°C). [Adediji and Ajewole (2008)] There are two terms on the right-hand side of equation (1.2) [Ajileye *et al* (2016)];

$$N_{dry} = 77.6\ \frac{P}{T} \text{ and } N_{wet} = 3.73 \times 10^5 \frac{e}{T^2} \tag{1.4}$$

The dry term N_{dry} depends only on pressure and temperature while the wet term N_{wet} varies with time and space and it is the dominant variable parameter because it depends on the presence of water vapour concentration and temperature of the atmosphere. These terms contributed 70% and the variability respectively to the total value of *N* [Willoughby *et al.* (2002)], more so the wet path gives an indication of landfall and cyclone movement when it close to the coast [Midya *et al.* (2013)]. Because radio signals refract over the whole signal path, hence the variation in any of these meteorological parameters causes significant changes in radio wave propagation [Priestley and Hill (1985)] and temperature and liquid water content influenced attenuation due to the cloud [Ojo and Owolawi (2015)]. Consequently, with respect to the lapse rate of temperature and other parameters, refractivity values decrease with increase in height. For accurate predictions of radio wave propagation, knowledge of the height profile of radio refractivity is required [Dockery (1988)].
The refractive index gradient, the rate of change of *N* with altitude is the primary importance in the determination of the path of propagation of a radio ray in the troposphere [Adediji and Ajewole (2008)]. It's parameter required by digital terrestrial point to point radio circuit for optimum performance [Lawrence *et al.* (2014)]. [Kaissassou *et al.* (2015)] established that the implementation of radar and other meteorological applications or telecommunications requires the knowledge of the vertical refractivity gradient.
The changes of radio refractivity N with height, *dN/dH* in the first- one kilometer above ground, can be determined from:

$$\frac{dN}{dH} = \frac{N_s - N(h)}{h - h_s} \tag{1.5}$$

where N_s is the refractivity at the soil surface (ground), N(h) is refractivity at altitude h, h_s is ground surface altitude, and h is the height above the ground surface level [Igwe and Adimula (2009)].

2 Research Methodology

The device called Davis 6162 wireless Vantage Pro2 Plus weather station, equipped with an Integrated Sensor Suite (ISS), was used for collecting data used for this study. It has a solar panel (including a battery as alternative source) and a wireless receiver (console) having a user interface data display,

and it contains a data logger connected to it which logged in the measured data via wireless radio connection at intervals of 30 minutes.
The ISS of the device housed the Sensors for the weather variables (pressure, temperature, relative humidity weather variables). The position of the devices was at five different altitudes (0, 50, 100, 150, and 200 m) for continuous measurement of the weather variables which are log in the logger and later downloaded to a personal computer for analysis. The data collection covered 24 hours each day from 00 hours to 2300 hours local time and was carried out for the period of four years (January 2007 to December 2009 and year 2011).
The collected relative humidity values were used to compute the water vapor pressure, e (hpa) by using equation 1.3. Equations 1.2 and 1.5 were used in computing radio refractivity and its gradient at the various altitudes respectively.

3 Results and Discussion

3.1 Diurnal Variation of Refractivity Gradient

Figs. 1(a-d) show the typical yearly mean value of the diurnal variation of refractivity gradient in the dry season period. The gradient increase steady from the hour of 8:30 hrs and 9:30 to 18:00 hrs, which may mainly due to the presence of the solar energy during these hours. In the year 2009, a regular increase of refractivity gradient was observed in the first two hours of the day before a gradual decrease till around 8:30 hrs which can be allied to temperature inversion across all the altitudes except at the 200 m height where it only declines slightly. Likewise, in the first four to six hours in the year 2008, refractivity gradient gradually increases across all altitudes with slight oscillatory decrease till 9:30 hrs, it slightly increases and then linearly decreases for the rest of the day. In the year 2007 and 2011, the refractivity gradient decreases gradually from 00 hrs to around 8:30 hrs and 6:00 hrs respectively. It started to increase and later with a slight oscillatory decrease from 18:00 till the rest hour of the day, this behavior is due to the presence of high relative humidity values as a result of absent of solar energy in the night time.

Similarly, the year 2007 also experience a trend of early hour decrease during the onset of the rainy season with a gradual increase of an oscillatory fluctuation from 10:30 hrs till the rest of the day with a sharp increase around 9:00 hrs across all the altitudes. While for the remainder of the years, the early hour's refractivity gradient experiences an increasing trend during this period in Akure (Figs. 2 a-d), that is due to temperature inversion observed during the period. The reversal is due to a high temperature associated with the commencement of the rainy season. It also made the gradient decreases gradually from 9:00 hrs till around 16:00 hrs before it started increasing and later dropped from 18:30 hrs till the end of the day across all the altitudes. The year 2011 recorded 158 N-unit/km as the maximum value at 14:30 hrs, and - 199 N-unit/km at 19:00 hrs in the year 2008 as the minimum refractivity gradient at the 50 m during the dry season. Meanwhile during the outset of the rainy season, the maximum and minimum value was recorded at the 50 m altitude in the year 2007 as 101 N-unit/km and - 148 N-unit/km around 8:30 hrs and 18:00 hrs respectively.

Figs. 3(a-d) shows similar trend during the rainy period, but the gradient begins to decrease and increase two hours earlier than that of the dry season, and at the outset of the wet period across all the altitudes. The high values of relative humidity are responsible for the observation in 1.3 and is corresponded to small values of refractivity gradient throughout the period investigated. Reversed is the case in the year 2008 at 100 m altitude and at 50 m height of the year 2011, the gradient increases from 9:00 to 14:00 hrs and 9:00 to 15:00 hrs respectively due to the occurrence of temperature inversion. It then gradually decreases in the year 2011 till the next morning while it

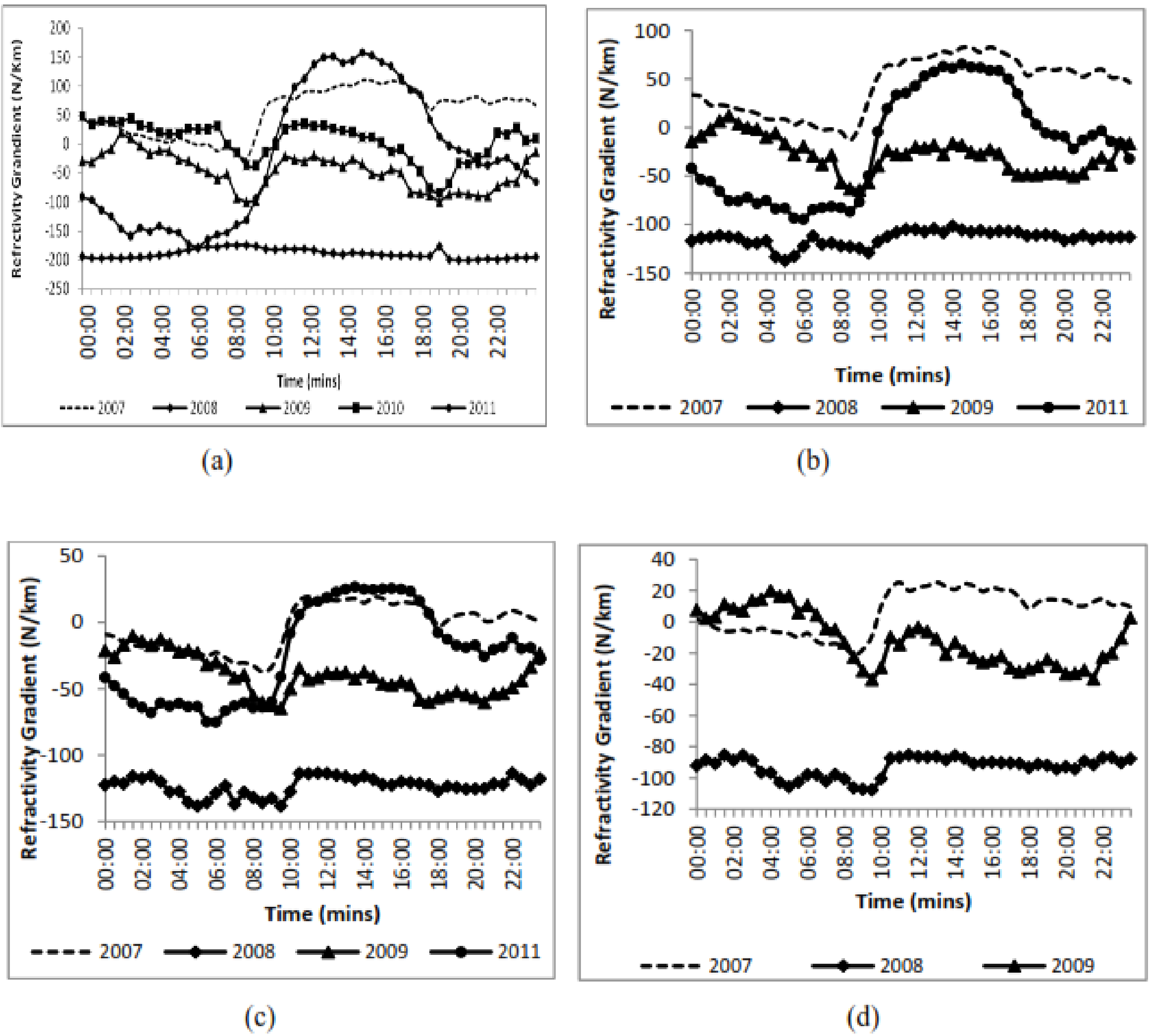

Figure 1: Diurnal Variation of refractivity gradient for a typical day in the dry season at: (a) 50 m (b) 100 m (c) 150 m (d) 200 m (January 2nd) from 2007 – 2011

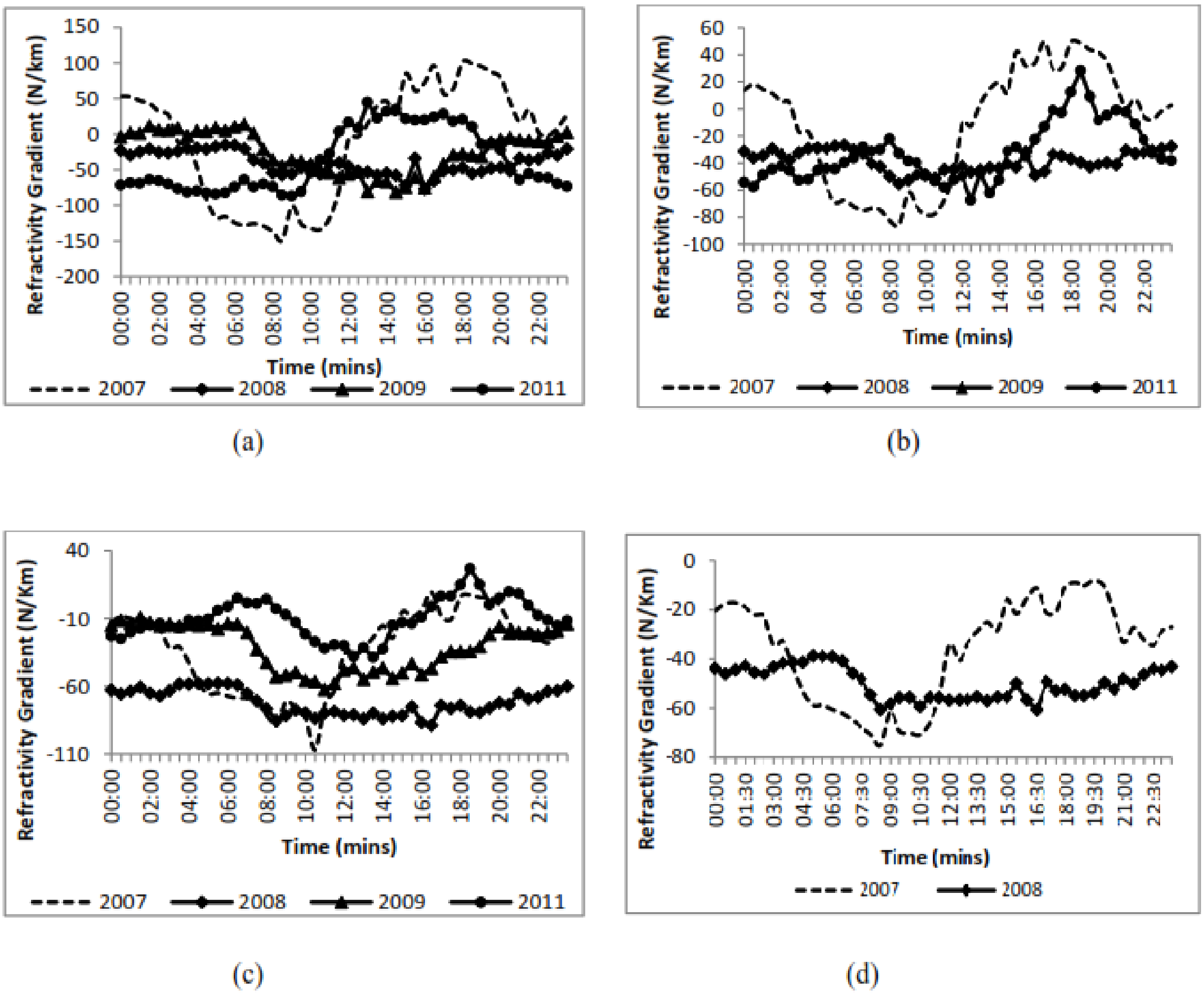

Figure 2: Diurnal Variation of refractivity gradient for a typical day during onset of the rainy season at: (a) 50 m (b) 100 m (c) 150 m (d) 200m from 2007 – 2009 and 2011

increased from 18:00 hrs till the next morning in 2008. During these periods, the maximum and the minimum value of the gradient was about 87 N units/km and - 286 at 12:30 hrs and 14:00 hrs in the year 2008 and 2007 at 100 m and 50 m altitude respectively.

The year 2011 recorded the highest value at a 50m altitude of about 158 N-units/km at 14:30 hrs, this was attributed to the dry season period known with high temperature alongside with the ground heat flux. During the dry season period, the year 2008 recorded the minimum value of the refractivity gradient of about - 199 N/km at 19:00 hrs. Meanwhile, in the rainy season, the year 2007 logged the lowest value across all the altitude at around 13:30 hrs to 14:00 hrs with the least value of about - 286 N/ km at 50m height.

3.2 Seasonal and Annual Variation of Refractivity Gradient

The figs 4 (a-d) showed a variation with the typical negative value of the refractivity gradient during the period of the investigation across all the altitudes. The refractivity gradient at all heights showed a gradual fall and rise between May and October which were the wet months with steeper fall of more negative values in the year 2007 (Figs. 4 a-d). It also shows that refractivity gradient is steeper with greater variability in the dry season than in the wet season. It was observed from April across all the altitudes in Akure, that refractivity gradient increased to May in each year which is due to the transitional period of the dry to the rainy season, known with high temperatures. The refractivity gradient decreases gradually between June and July across all the altitudes during the four years of study, which can be ascribed to the period of the high value of humidity in the atmosphere, often associated with intense rainfall. Meanwhile during the periods (December to January) of intense harmattan in this part of the globe which are often characterized by dry day, freezing nights and morning hours, the refractivity gradient was observed to increase slightly.

The annual variation as shown in Fig. 5 displays a common trend across 50 m, 100 m, and 200 m altitudes from the year 2007 to 2009 whereby the refractivity gradient increased gradually from the year 2007 to 2008 and then decreased slightly towards the year 2009 with almost a linear decrease towards the year 2011 except at 200 m. At 150 m, the gradient had a similar trend from 2007 till 2009 with a steeper increase till 2011. The year 2007 records the lowest value of refractive index gradient during the period of investigation, and it ranges between - 70 to - 165 N-units/km. This occurrence in the year 2007 shows that the intensity of the Harmattan was very high in the year than the other years investigated. The highest observed value of refractive index gradient about - 18 N-units/km during the studied period was in the year 2011 at the 150 m altitude and about - 165 N-units/km at the 50 m level as the lowest value in the year 2007.

3.3 Variation of Refractivity Gradient with Height

The investigation of refractivity gradient over Akure at various heights ranging from the ground surface to 200 m has been carried out. The observation shows occurrence (Fig. 6) of anomalous propagation of radio signals at various antenna heights. In the year 2007, radio signal at an antenna height of 50 m and 100 m are likely to be trapped. The trapping is due to the existence of surface duct between the ground surface and 100 m altitude. An elevated duct between antenna heights of 100 m and 150 m implies that radio signals are unrestrictedly received at far distances, even beyond the expected coverage area of the transmitter and may cause undue interference to other channels operating at the same frequency in the other location where the signals are received.
The existence of sub-refraction at 150 m became a Normal refraction at 200 m altitudes. It implies that the receiver unrestrictedly receives the propagated signal at the 200 m elevation but a bit thorny

Figure 3: Diurnal Variation of refractivity gradient for a typical day during the rainy season at (a) 50 m (b) 100 m (c) 150 m (d) 200m (July 2nd) from 2007 – 2009 and 2011

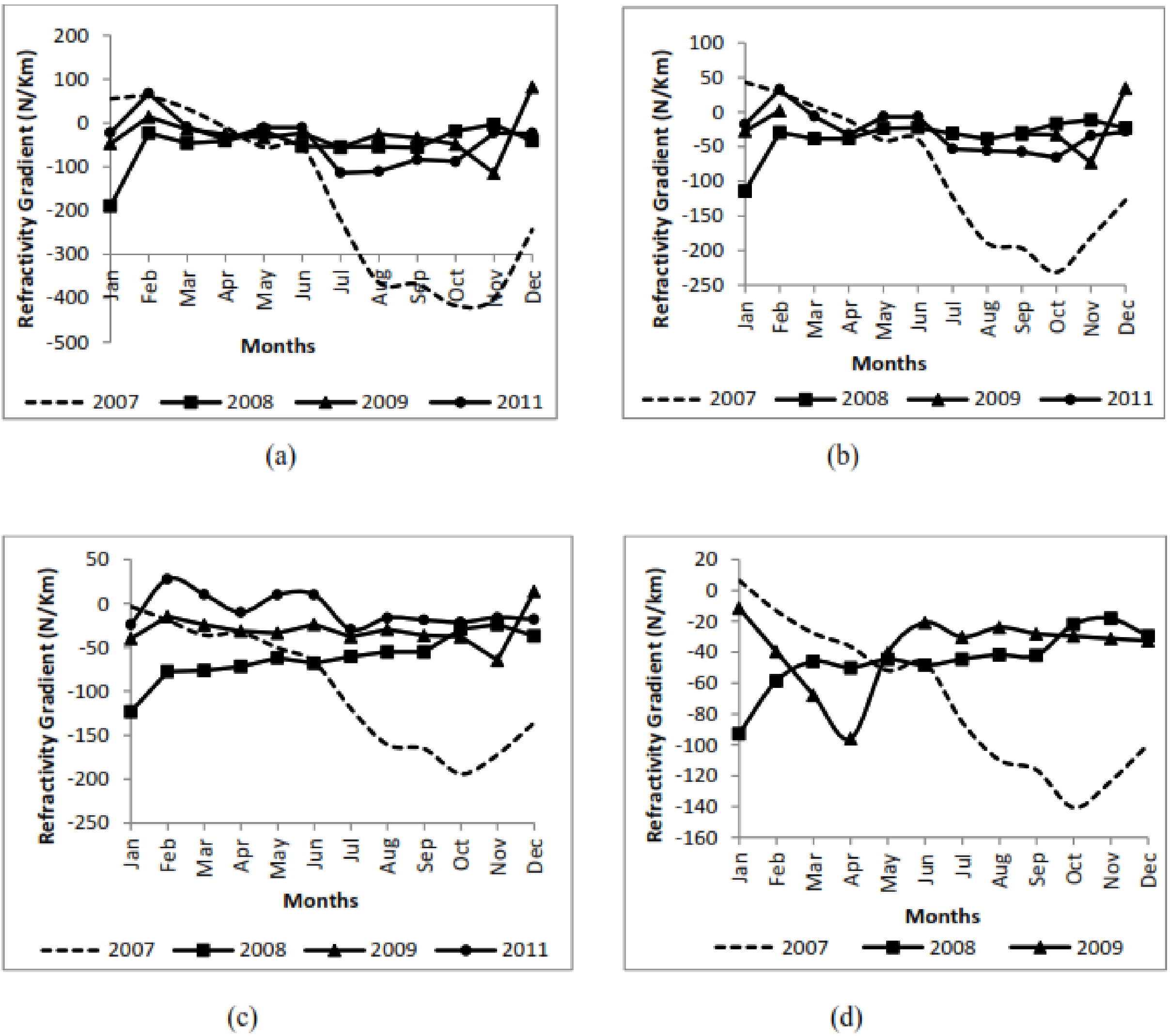

Figure 4: Seasonal variation of refractivity gradient at: (a) 50 m (b) 100 m (c) 150 m (d) 200m from 2007 – 2009 and 2011

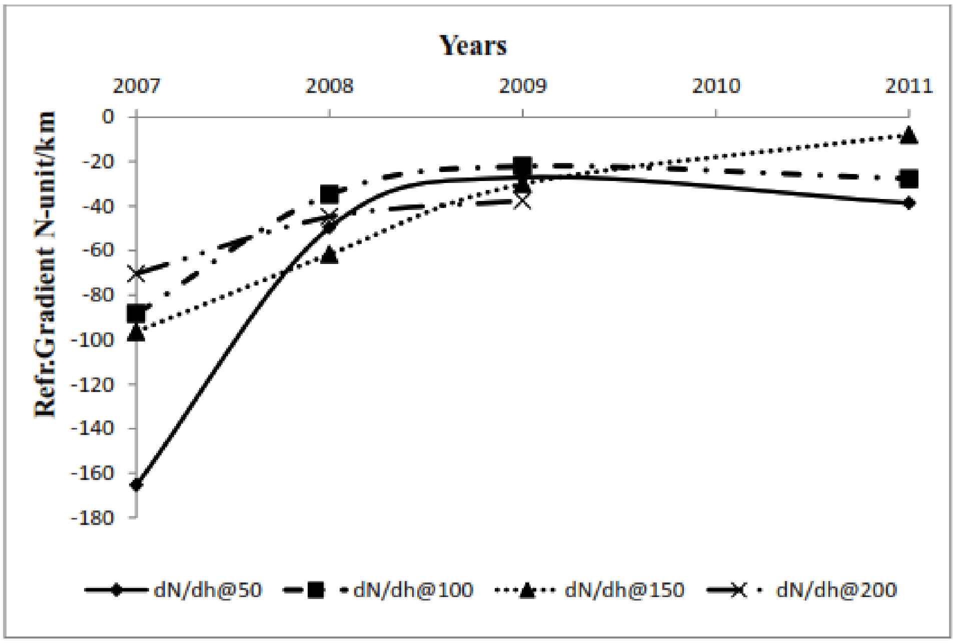

Figure 5: Annual variation of refractivity gradient over Akure (2007 – 2009 and 2011)

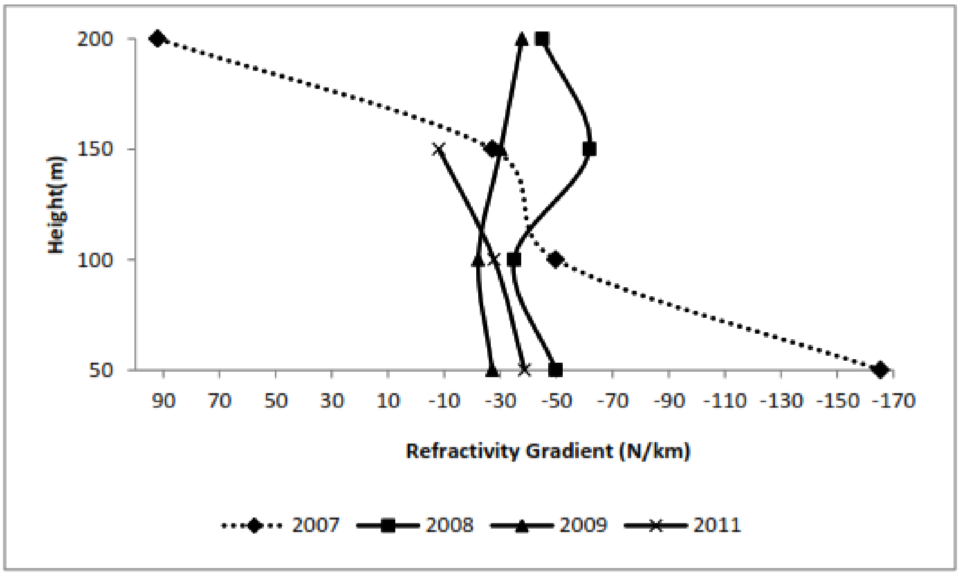

Figure 6: Variation of Refractivity Gradient with height from 2007 – 2009 and 2011

at 150 m which are the same as that experienced across all the heights in the year 2009, 2011 and at 100 m in the year 2008. Due to temperature inversion and rapidly decreased of water vapor content with height at 50, 150 and 200 m in 2008, the signal propagated at this altitude will be received at a very long range (far beyond the receiver).

4 CONCLUSIONS

Refractive index gradient experiences diurnal, seasonal and annual variation because meteorological parameter varies significantly with height which also affects its vertical distribution. Analysis of four-year data of the meteorological parameter over Akure shows the following below.

a In the subsection (3.1), it was shown that between the hours of 8:30 and 9:30 to 18:00 during the dry season, the refractivity gradient increases steadily. Two hours earlier to these times during the rainy seasons, it decreases across all the altitudes during the investigated periods.

b Also, 50 m height recorded the highest values of the gradient as well as the lowest values. The high value of temperature during the onset month of the rainy season results to the high value of refractivity gradient in the months.

c In the subsection (3.2), it was observed that the variability of the refractive index gradient is steeper in the dry season months than in the wet season months.

d In the subsection (3.3), the atmospheric propagation conditions at 150 m are suspected to be a sub-refractive condition.

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