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Influence of some meteorological factors on tropospheric radio refractivity over a tropical location in Nigeria

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सार – नाइजीरिया के अकुर (7.15° उत्तर, 5.12° पूर्व) में निर्मित डेविस 6162 वायरलेस वैण्टेज प्रो 2 वेदर स्टेशन्स (इंटीग्रेटेड सेन्सर स्यूट, ISS) से मापे गए वायुमंडलीय दाब, तापमान और सापेक्षिक आर्द्रता से रेडियो अपवर्तकता की गणना की गई है। ये माप धरातल से आरंभ कर 200 मी. की ऊँचाई तक, 50 मी. के अंतरालों पर पाँच विभिन्न स्तरों से लिए गए है। इस शोध के लिए पाँच वर्षों (जनवरी 2007 से दिसम्बर 2011 तक) के आँकड़ों का उपयोग किया गया है। इस शोध से प्राप्त हुए परिणामों से यह पता चला है कि जलवाष्प दाब का रेडियो अपवर्तकता के सभी स्तरों पर अत्यधिक प्रभाव रहा है। तापमान अपवर्तनांक को भी प्रभावित करता है क्योंकि अपवर्तनांक सूचकांक के उच्च मान जो नवम्बर के संक्रमण काल वाले महीनों और दिसम्बर/जनवरी के हरमैटन अवधि में रिकार्ड किए गए हैं वे प्राय: उच्च वायु आर्द्रता और निम्न जलवाष्प तत्व के साथ संबद्ध होते हैं। वायुदाब का इस पर अत्यल्प प्रभाव पड़ता हैं क्योंकि मापे गए वायुदाब रेडियो अपवर्तकता के मान पर बहुत कम बदलाव को दर्शाते हैं।

ABSTRACT. Radio refractivity is computed from the measurements of atmospheric pressure, temperature and relative humidity made in Akure (7.15° N, 5.12° E), Nigeria using Davies 6162 wireless vantage Pro2 Weather Stations (Integrated Sensor Suite, ISS). Measurements are taken at five different levels starting from the ground surface to 200 m altitude at intervals of 50 m. Five years of data (January 2007 - December 2011) were utilised for the study. Results show that at all the levels, water vapour pressure has the most significant influence on radio refractivity. Temperature also influences refractivity as high values of refractive index are recorded in the transition months of November and Harmattan period of December/January that are usually associated with high air humidity and low water vapour content. Pressure has the least influence, since significant changes in the measured value of pressure often correspond to minimal changes in value of radio refractivity.

Key words – Troposphere, Refractivity, Pressure, Water vapour, Temperature.

1. Introduction

The troposphere is the region of the atmosphere, where changes of temperature, pressure and humidity, as well as clouds and rain, influence the way in which radio waves propagate from one point to another (Hall, 1979). In the troposphere, ionization of gases is negligible because ultraviolet (UV) radiation reaching in this region is negligibly small. Due to the presence of gases like oxygen and water vapour which have electric dipole moments, the troposphere has a dielectric constant and hence a refractive index. The water vapour molecules in the troposphere are polar in nature, possessing permanent dipole moment (Giri, *et al*., 2007). All other gases are non-polar and the dipole moment is induced among these gases when electromagnetic waves propagate through the troposphere. These molecules re-orient themselves according to the polarity of the propagating wave causing a change in the refractive index of the troposphere (Saha, *et al*., 2005).

Tropospheric radio wave propagation is to a large extent influenced by the structure of the refractive index of the atmosphere and the refractive index is a function of pressure, temperature and water vapour pressure (Saha *et al*., 2005, Tomar, 2012). The bending of electromagnetic waves due to inhomogeneous spatial distribution of the refractive index of air causes adverse effects on radio waves. Examples of these effects are multipath fading, interference, attenuation due to diffraction on the terrain obstacles, radio holes, and so on (Mini and Prabhakaran Nayar, 2012). These effects significantly impair radio communication, navigation and radar systems.

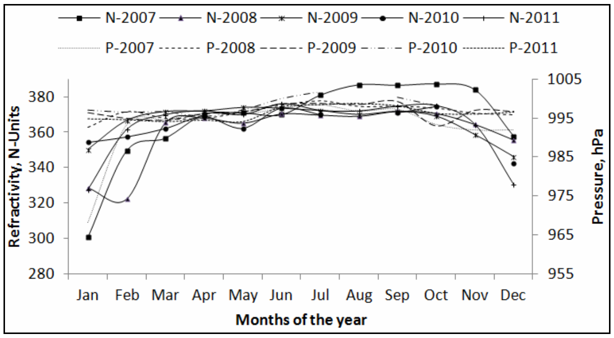

Fig. 1. Seasonal variation of refractivity with pressure at the surface from 2007 to 2011

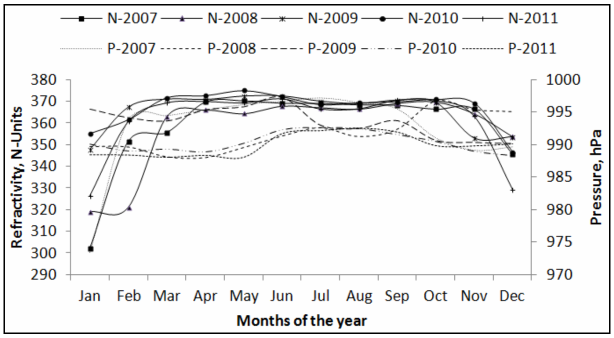

Fig. 2. Seasonal variation of refractivity with pressure at 50 m altitude from 2007 to 2011

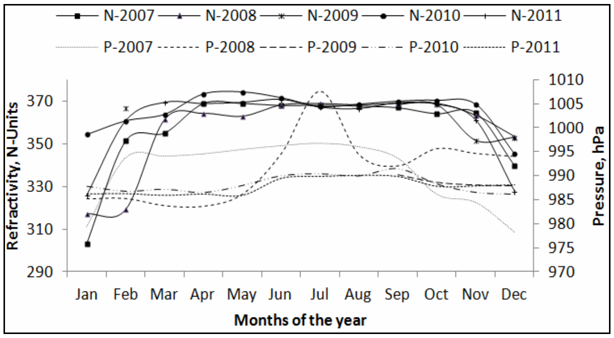

Fig. 3. Seasonal variation of refractivity with pressure at 100m altitude from 2007 to 2011

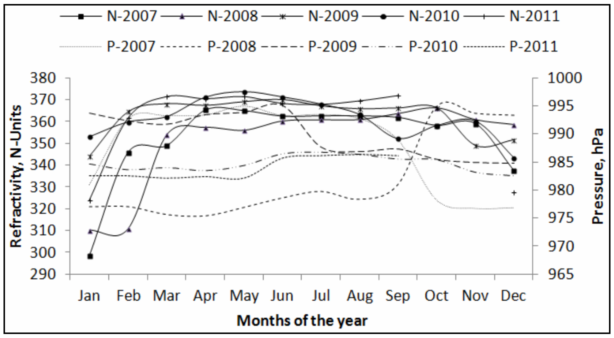

Fig. 4. Seasonal variation of refractivity with pressure at 150 m altitude from 2007 to 2011

Most of the earlier works done on the subject of radio refractivity in Nigeria are on surface refractivity and are based on radiosonde data (Owolabi and Williams, 1970; Kolawole, 1980; Babalola, 1996; Willoughby, *et al.*, 2002; Oyedum *et al.*, 2009). The information obtained from radiosonde measurements generally lacks the spatial and temporal resolutions which are necessary for the measurement of small-scale variations particularly in the lower atmosphere (Lowry *et al.*, 2002). Furthermore, it is generally recognized that radiosonde measurements do not have a sufficiently high degree of accuracy to be completely acceptable for use in observing changes in the degree of stratification of the very lowest layers of the atmosphere (Hajj *et al.*, 2002).

Recently, some experimental studies on this subject were carried out in Akure, Nigeria by Falodun and Ajewole, 2006; Adediji and Ajewole, 2008; Adediji and Ajewole, 2010; Adediji *et al.*, 2011; Ayantunji *et al.*, 2011. These studies, though brought out some interesting results, but lacked information on how precisely changes in weather patterns influence radio refractivity. The present study is focused on better understanding of the relative importance of various meteorological parameters that influence tropospheric radio refractive index with a case study of Akure, Nigeria.

2. Tropospheric radio refractive index

The radio refractive index, n, is defined as the ratio of the speed of propagation of the radio energy in vacuum, c, to the speed, v, in a specified medium (Bean and Dutton, 1968).

$$n = c/v \quad (1)$$

In the troposphere, the refractive index is a function of temperature, barometric pressure and water vapour pressure. It has both dry and moist air components. For dry air, the refractive index is given as;

$$(n - 1) \times 10^6 = N = 77.6\ P/T \quad (2)$$

The term N called the radio refractivity is a parameter used to describe the spatial and temporal variation of the refractive index.

For moist air, the radio refractivity N is given by:

$$N = 3.73 \times 10^5\ e/T^2 \quad (3)$$

where, the parameters P, T and e are barometric pressure (hPa), absolute temperature (K) and partial pressure of water vapour in (hPa) respectively.

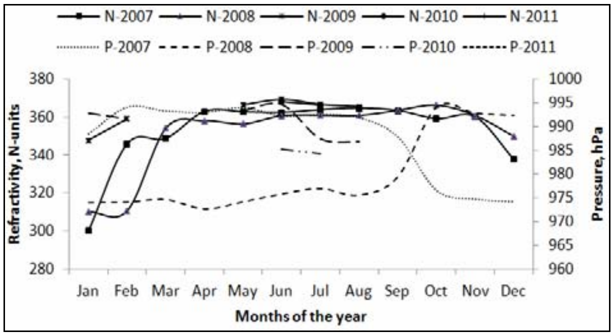

Fig. 5. Seasonal variation of refractivity with pressure at 200 m altitude from 2007 to 2011

The radio refractivity of air can therefore be calculated from the expression:

$$N = 77.6\ P/T + 3.73 \times 10^5\ e/T^2 \tag{4}$$

while the partial pressure of water vapour is calculated using the expression (ITU-R, 2004):

$$e = H \times \frac{6.1121\exp\left[\dfrac{17.502t}{t+240.97}\right]}{100} \tag{5}$$

where, t is temp. (°C) and H is relative humidity (%).

3. Data and methodology

Five years of *in-situ* measurements of tropospheric temperature, pressure and relative humidity for the period 2007 to 2011 are used for the study. The site of the study is located at the old premises of the Nigerian Television Authority (NTA) at Iju in Akure North local government area of Ondo State. The instrument used for the measurements is the Davis 6162 Wireless Vantage Pro2 equipped with the Integrated Sensor Suite (ISS), a solar panel (with an alternative battery source) and the wireless console. The console is connected to a computer, through which the stored data are downloaded. The ISS houses the sensors for pressure, temperature, relative humidity, UV index and dose, solar radiation, rain rate, wind speed and direction, among others and the Sensor Interface Module (SIM). The SIM contains electronics that measure and store values of weather variables for transmission to the console via radio. The measurements at fixed point in the vertical are done using a high tower. The ISSs are positioned at the ground surface and at different heights (50 m, 100 m, 150 m and 200 m) on the tower, for continuous measurement of 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 taken with a time interval of 30 minutes. Thus, there are forty-eight (48) observations of each parameter in a day. The error margin of the ISS device for temperature, pressure and relative humidity are ± 0.1 °C, ± 0.5 hPa and ± 2% respectively. More details about the experimental location and the instrumentation set-up is available in Adediji and Ajewole, (2008).

Meteorological parameters; pressure P, temperature T and relative humidity H are measured directly by means of the sensors while the radio refractivity and partial pressure of water vapour are derived from expressions (4) and (5) respectively. Relative humidity and the saturated vapour pressure, e_s are related as;

$$H = e/e_s \times 100\% \tag{6}$$

The saturated vapour pressure, e_s is derived by the Clausius-Clapeyron equation;

$$e_s\,(T) = Ae^{-B/T} \tag{7}$$

where,

$A = 2.53 \times 10^8$ kPa, $B = 5.42 \times 10^3$ K over water &

$A = 3.41 \times 10^9$ kPa, $B = 6.13 \times 10^3$ K over ice.

The measured and computed data were then used to investigate the distribution of pressure, temperature and water vapour pressure as well as the influence of each of these parameters on radio refractivity.

4. Results and discussion

4.1. *Influence of pressure on radio refractivity*

The seasonal variation of refractivity with pressure for the years 2007 to 2011 at the surface and at 50 m, 100 m, 150 m and 200 m altitudes are shown in Figs. 1-5. It is observed that high changes in values of pressure do not correspond to high changes in the values of refractivity. For instance in 2007 at the surface, between January and February, pressure experienced only 2.58% increase whereas, during the same period, refractivity experienced 15.57% increase. Peak to peak analyses of these curves also show significant irregularities in the variation patterns of refractivity with pressure. Only the months of February, March, April, May and September show peak to peak alignment in 2007 at the surface, other months are very irregular. Similarly in 2008, the peak to peak variation is more irregular, with only October and November as the months of appreciable alignment. This trend of irregularity was observed at all the levels for the period considered for this work but with varying

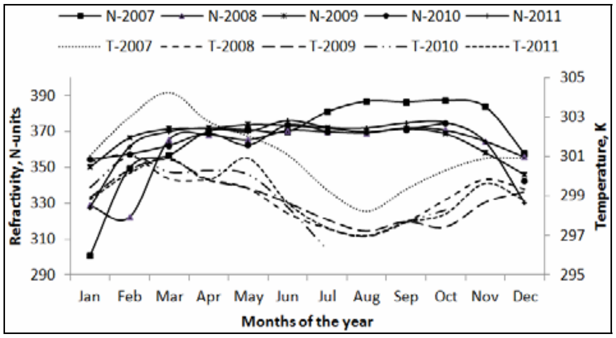

Fig. 6. Seasonal variation of refractivity with temperature at the surface from 2007 to 2011

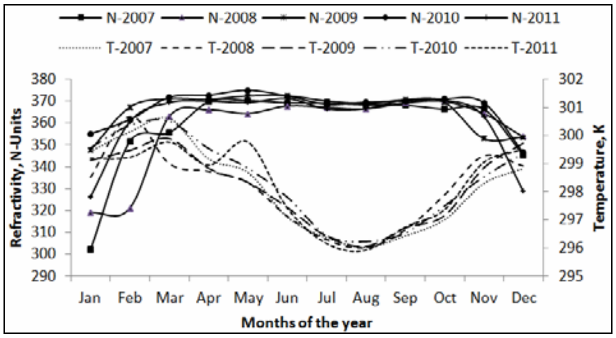

Fig. 7. Seasonal variation of refractivity with temperature at 50 m altitude from 2007 to 2011

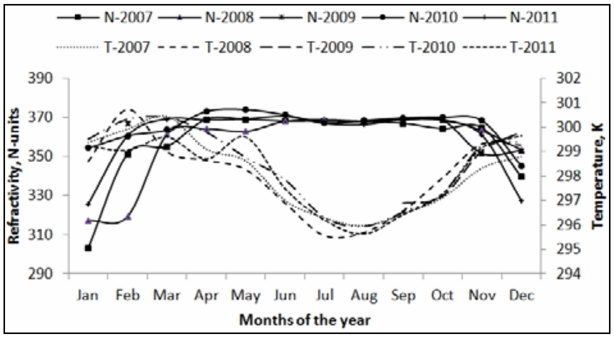

Fig. 8. Seasonal variation of refractivity with temperature at 100 m altitude from 2007 to 2011

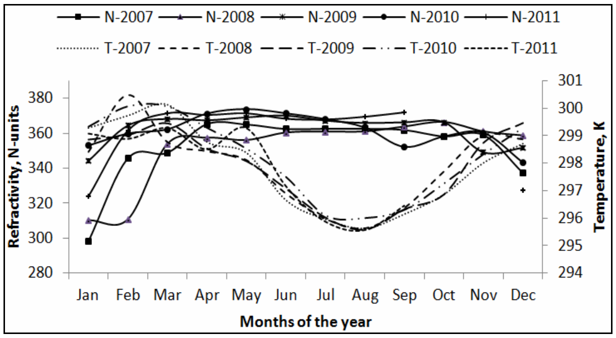

Fig. 9. Seasonal variation of refractivity with temperature at 150 m altitude from 2007 to 2011

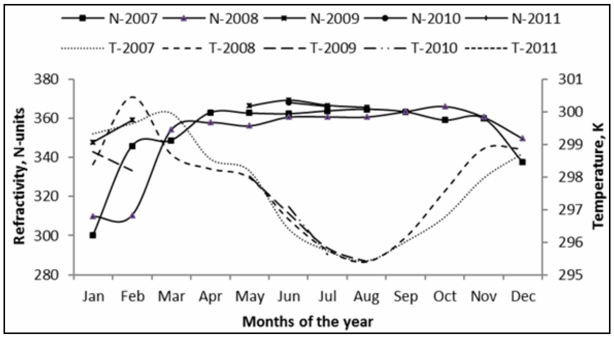

Fig. 10. Seasonal variation of refractivity with temperature at 200 m altitude from 2007 to 2011

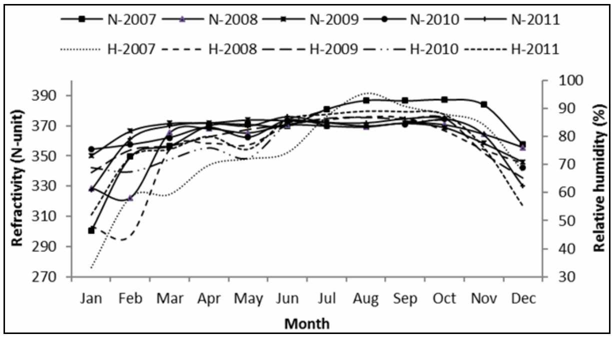

Fig. 11. Seasonal variation of refractivity with relative humidity at the surface from 2007 to 2011

intensities and times of occurrence. As seen at 50 m altitude (Fig. 2), the values of pressure in 2009 between January and June were significantly higher than those of other years, but it did not influence refractivity values because when pressure suffered a significant depression between July and September, refractivity was steady. This fact is also evident at 100 m, 150 m and 200 m where significant increase or decrease in pressure values did not translate into any meaningful changes in values of radio refractivity. This shows that variations in pressure have minimal influence on changes in refractivity.

4.2. *Influence of temperature on radio refractivity*

The seasonal variation of refractivity with temperature for the years 2007 to 2011 at the surface and at 50 m, 100 m, 150 m and 200 m altitudes are shown in Figs. 6-10. As shown in the figures, high values of temperature correspond to low values of refractivity and vice versa. However, during the harmattan periods (December and January), it is observed that high values of temperature correspond to high values of refractivity.

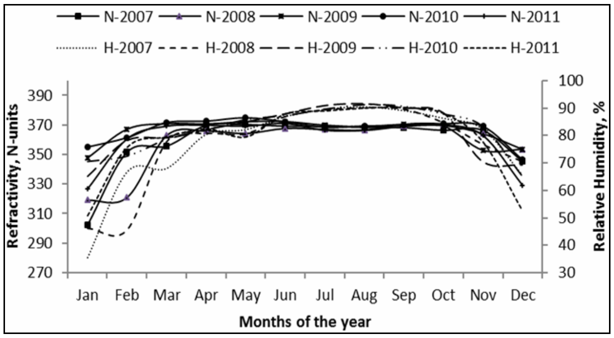

Fig. 12. Seasonal variation of refractivity with relative humidity at 50 m altitude from 2007 to 2011

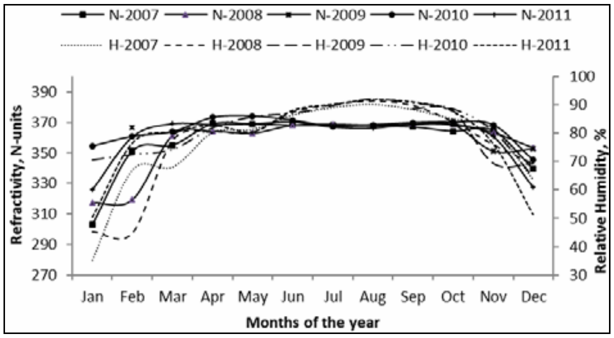

Fig. 13. Seasonal variation of refractivity with relative humidity at 100 m altitude from 2007 to 2011

For the periods under consideration, it was observed that both temperature and refractivity have steady patterns. Values of temperature were observed to increase steadily from January to February/March and thereafter decreased sharply till August, and then began to increase till November/December. Values of refractivity equally increased sharply from January to February, then gradually till around May when it became steady until October before it began to drop till around December/January. Peak to peak analyses showed that during the dry season months of November to February, there is observed correspondence between temperature and refractivity. This shows that temperature has significant contribution to refractivity values.

4.3. *Influence of water vapour pressure on radio refractivity*

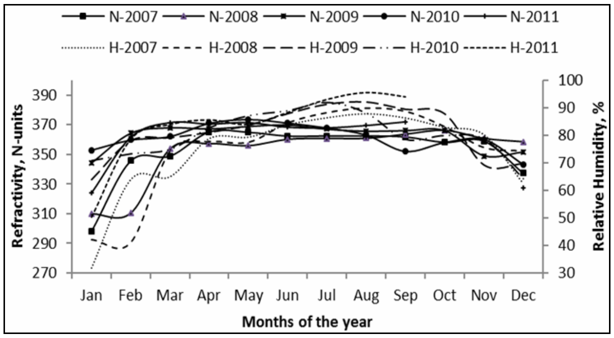

Fig. 14. Seasonal variation of refractivity with relative humidity at 150 m altitude from 2007 to 2011

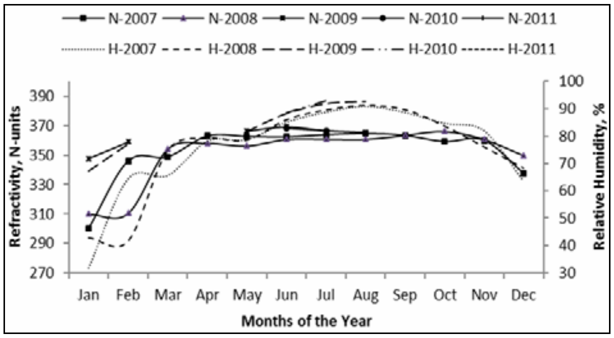

Fig. 15. Seasonal variation of refractivity with relative humidity at 200 m altitude from 2007 to 2011

The ratio of partial pressure of water vapour in a gaseous mixture of air and water vapour to the saturated vapour pressure of water at a given temperature is known as relative humidity. Relative humidity is expressed as a percentage and it is given in equation (6). Due to the inter-dependence of water vapour pressure and relative humidity, the graphical representations of variation of refractivity with relative humidity from the surface to 200 m altitude at 50 m interval are presented in Figs. 11-15. It is observed that both relative humidity and refractivity values increased gradually from January till around March, thereafter the values appear to be steady till October, before descending gradually form October till December at all the levels and years of study. Similarly, peak to peak analyses showed that both refractivity and relative humidity have their peak and off peak values around August and December respectively. Similarly, high values of relative humidity correspond to high values of refractivity throughout the period of this study. This established the fact that variations in relative humidity account most significantly for changes in radio refractivity.

5. Conclusions

The tropospheric radio refractivity is affected by meteorological factors such as atmospheric pressure, temperature and water vapour pressure (relative humidity). Atmospheric pressure and water vapour pressure experience rapid decrease with height while the rate of decrease of temperature with height is less rapid, in effect, radio refractivity decreases with increasing height. The implication of this decrease in radio refractivity with altitude is that the velocity of any propagating wave within the troposphere increases with height, causing such radiowaves to bend towards the earth (Bayong, and Djakawinata, 1999). Five years of data for the period 2007-2011 collected at Akure, Nigeria have been studied to understand the influence of meteorological parameters on Radiowave propagation.

The analysis of influence of meteorological factors on refractivity shows water vapour pressure has the most significant influence on radio refractivity. Moreover, pattern of distribution of water vapour pressure follows the same trend as that of refractivity. Temperature also has considerable influence on refractivity as high values of refractive index are recorded in the months of November, December and January which is the months characterized by high temperatures and are referred to as the dry season in this region of the globe.

Lastly, Pressure has the least influence since significant changes in the measured value of pressure often correspond to minimal changes in value of radio refractivity.

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