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

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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 terrain obstacles, radio holes, and so on (Mini and Prabhakaran Nayar, 2012). These effects significantly impair radio communication, navigation and radar systems.
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).

\[
 n = \frac{c}{v} \tag{1}
\]

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:

\[
(n - 1) \times 10^6 = N = 77.6 \frac{P}{T} \tag{2}
\]

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:

\[
N = 3.73 \times 10^5 \frac{e}{T^2} \tag{3}
\]

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:

\[ N = 77.6 \frac{P}{T} + 3.73 \times 10^5 \frac{e}{T^2} \]  \hspace{1cm} (4)

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

\[ e = H \times \frac{17.5021}{t+240.97} \] \hspace{1cm} (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:

\[ H = \frac{e}{e_s} \times 100\% \] \hspace{1cm} (6)

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

\[ e_s(T) = A e^{-B/T} \] \hspace{1cm} (7)

where,

\[ A = 2.53 \times 10^8 \text{ kPa}, \quad B = 5.42 \times 10^3 \text{ K} \text{ over water} \]
\[ A = 3.41 \times 10^9 \text{ kPa}, \quad B = 6.13 \times 10^3 \text{ K} \text{ over ice} \]

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
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.
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

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 interdependence 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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References

Adediji, A. T. and Ajewole, M. O., 2008, “Vertical Profile of Radio Refractivity Gradient in Akure South-Western Nigeria”, Progress in Electromagnetic Research, C 4, 157-168.

Adediji, A. T. and Ajewole, M. O., 2010, “Microwave Anomalous Propagation (AP) Measurement over Akure South-Western Nigeria” Journal of Atmospheric and Solar-Terrestrial Physics, 72, 5-6, 550-555.

Adediji, A. T., Ajewole, M. O. and Falodun, S. E., 2011, “Variation of Radio Refractivity Gradient and Effective Earth Radius Factor (k-factor) over Akure, South Western Nigeria”, Journal of Atmospheric and Solar-Terrestrial Physics, 73, 16, 2300-2304.

Ayantunji, B. G., Okeke, P. N. and Urama, J. O. 2011, “Diurnal and Seasonal variation of surface refractivity over Nigeria”, Progress in electromagnetic research, B 30, 201-222.

Babalola, M. T., 1996, “Statistics of Radio Refractivity Gradient in the Lower Atmosphere in Nigeria”, Nig. Journ. Physics, 85, 7-20.

Bayong, T. H. K. and Djakawinata, S., 1999, “Influence of Meteorological Factors on Refractivity over Indonesia”, Journal Matematika & Sains, 4, 1, 1-12.

Bean, B. R. and Dutton, E. J., 1968, “Radio Meteorology”, Dover Publications Inc., New York (USA), 9-13.

Falodun, S. E. and Ajewole, M. O., 2006, “Radio Refractive Index in the Lowest 100 m Layer of the troposphere in Akure, South Western Nigeria”, Journal of Atmospheric and Solar-Terrestrial Physics, 68, 2, 236-243.

Giri, R. K., Meena, L. R., Bhandari S. S. and Bhatia, R. C., 2007, “Integrated Water Vapour from GPS”, Mausam, 58, 1, 101-106.

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, 64, 451-469.

Hall, M. P. M., 1979, “Effects of the Troposphere on Radio Communication” Peter Peregrins Ltd., U. K. & U. S., 1-22.

ITU-R, 2004, “The radio refractive index: its formula and refractivity data” Recommendation P, 453-459.

Kolawole, L. B., 1980, “Climatological Variations of Surface Refractivity in Nigeria”, Bull. Nig. Inst. Phys, 4, 97-117.

Lowry, Anthony R., Chris, Rocken and Sergey, V. Sokolovskiy, 2002, “Vertical profiling of atmospheric refractivity from ground-based GPS”, Radio Science, 37, 3, 13-1-13-19.

Mini, V. K. and Prabhakaran Nayar, S. R., 2012, “An Analysis of Monthly and Synoptic Scale Variation of Radio Refractive Index During Pre-Monsoon and Monsoon Onset Phase, Mausam, 63, 3, 508-510.

Owolabi, I. E. and Williams, V. A., 1970, “Surface Refractivity Patterns in Nigeria and The Southern Cameroon” J. West African Science Association, 15, 3-17.

Oyedum, O. D., Igwe, K. C., Echie, J. O. and Moses, A. S., 2009, “Preliminary Results of Surface Refractivity in Minna, Niger State, Nigeria”, Proceedings of Second Annual Conference of the Nigerian Union of Radio Science, 19-24.

Saha, K., Raju, S., Parameswaran, K., 2005, “Neutral Atmospheric Refraction on Microwave Propagation and its Implication on GPS Based Ranging System”, Proceedings of the XXVIIIth General Assembly, New Delhi.

Tomar, M. S., 2012, “Measurement and Analysis of Radio Refractive Index over Patiala during Monsoon Season with Respect to its Diurnal and Monthly Characteristics”, Mausam, 63, 2, 334-338.

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, 64, 417-425.