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Day - To - Day and Seasonal Variations of Tropospheric Radio Refractivity in Lagos, South Western, Nigeria

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***Abstract* - The investigation of day to day and seasonal tropospheric radio refractivity variation was carried out in Lagos using a three year period (January 2014 to December 2016) surface data. The data were collected using Campbell scientific automatic weather instrument. The CR1000 data logger type is used for measurement, and data storage is for five minute update cycle. The results of the analysis show that the high value of refractivity observed in the dry season can be attributed to the presence of water vapor in the air that causes evaporation from the Atlantic Ocean that covers the entire area. It was also revealed that the variation of refractivity in Lagos is mostly influenced by the variation of temperature and pressure with little contribution of relative humidity.**

Keywords: Troposphere, Refractivity, Temperature, pressure, relative humidity, Surface data.

I. INTRODUCTION

The system of communication can be divided into three namely the propagation channel, the receiver and transmitting system. The quality of the information received at the receiver depends on how much the signal is distorted in the propagation channel. In the case of transmission through the troposphere, the properties cannot be modified. This call for the need for adequate knowledge of the response of the radio signals to variation in the troposphere.

Tropospheric refraction relies on the variations in space of the refractive index. The radio refractive index is defined as the ratio of the speed of propagation of radio energy in a vacuum to the speed in a specified medium. According to Adediji and Ajewole, (2008), radio wave propagation is determined by changes in the refractive index of air in the troposphere. In the troposphere, some factors which influence the radio frequency or radio wave signal propagation include relative humidity, temperature and atmospheric pressure. Thus, according to Saha, Raju and Parameswaran (2005) and Tomar (2012), refractivity variation in the troposphere is a function of relative humidity, pressure, and temperature.

The study of the tropospheric radio refractivity has stimulated much interest because of its influence on radio wave communication in the troposphere. Hall (1979) defined troposphere as part of the atmosphere where changes in the meteorological parameters such as relative humidity, temperature and pressure and other factors like clouds and rain contribute to the variation of radio wave progation from one place to another.

In the work by Adeyemi and Adedayo (2005) on atmospheric radio refractivity and water vapour density at Oshodi, a coastal area in Southern Nigeria and Kano, a semi-arid, sub-Sahel area in the Northern Nigeria, it was reported that atmospheric radio refractivity is generally high during the rainy season at all the levels of the atmosphere considered while its values fall during the harmattan period. Ekpe, Agbo, Ayantunji, Yusuf and Onugwu (2010) studied the variation of tropospheric surface refractivity at Nsukka. Data were collected over a twelve-month period using the Vantage PRO II Automatic Weather Station. Results of their analysis showed that the surface refractivity is generally higher in the wet season than in the dry season. They also observed that a change in temperature influences refractivity much more than a change in either humidity or pressure. Bawa, Ayantunji, Mai-Unguwa, Galadanchi and Shamsuddeen (2015) on studying the average hourly variation of radio refractivity variations across some selected cities in Nigeria including Lagos, showed that dry term which is a function of pressure is the major driving force influencing diurnal refractivity variation over Lagos during the rainy season. Akpootu and IIiyasu (2017) estimated the tropospheric radio refractivity and its variation with meteorological parameters over Ikeja, Nigeria using the recommended International Telecommunication Union (ITU) method. Their results indicated that the radio refractivity value during the rainy season is higher than the dry season.

However, the advent of mobile communication in Nigeria, called Global System of Mobile Communication (GSM) and other Code Division of Multiple Access (CDMA) and the increase in the number of Television (TV) and Frequency

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Modulation (FM) stations operating in the very high frequency (VHF) and ultra high frequency (UHF) bands has increased the complexity of frequency distribution. Hence, studying the tropospheric radio refractivity variation is very essential to enable the industry to design sustainable and suitable radio communication systems. This work focuses on day to day and seasonal variations of tropospheric radio refractivity in Lagos, south western, Nigeria.

II. DATA COLLECTION

The data used for this work were obtained from the Centre for Atmospheric Research (CAR), Kogi State University Campus, Anyigba, which is an activity centre of the National Space Research and Development Agency (NASRDA), Abuja, Nigeria. We studied the day to day and seasonal variations of tropospheric radio refractivity in Lagos, Nigeria using January 2014 – December 2016 surface data collected by means of Campbell scientific automatic weather instrument. The CR1000 data logger type is used for measurement and data storage were five minute interval. The records cover 24 hours each day from 00 hours to 2300 hours local time. The data collected were averaged over each hour to give twenty four data points representing diurnal variations for each day of the year. The hourly data for each day is further averaged to give a data point for the day and the average were taken for all the period investigated to give the average diurnal variation of refractivity. The daily data average was also taken over the month to give a data point for each month which was used to determine the average monthly and seasonal variations.

III. THEORETICAL BACKGROUND

The refractive index of the troposphere is tremendously important in predicting performance of terrestrial radio links. The variation of refractivity in the troposphere is determined by the variations of temperature, relative humidity and pressure. The temperature in Kelvin (K), relative humidity in percentage (%) and pressure in millibar (mb) were the input parameters used to calculate the radio refractivity (N-units).

The atmospheric radio refractivity can be computed using the ITU-R (2016): formula

$$N = N_{dry} + N_{wet} = \frac{77.6}{T}\left(P + 4810\frac{e}{T}\right)(N - units) \quad 1$$

The dry term, N_{dry}, of radio refractivity is given by:

$$N_{dry} = 77.6\frac{P}{T} \quad 2$$

And the wet term, N_{wet}, by:

$$N_{wet} = 373256\frac{e}{T^2} \quad 3$$

Where P is the pressure in millibar (mb), e is the water vapour pressure in hector Pascal (hPa), and T is temperature in Kelvin (K).

The water vapour pressure, e is given by

$$e = \frac{RH e_s}{100} \quad 4$$

Where RH is relative humidity in percentage (%) and e_s is the saturated vapor pressure given by

$$e_s = 6.1121exp\left\{\frac{17.502\,t}{t+240.97}\right\} \quad 5$$

Where t is the value of the temperature in degree Celsius.

The refractive index, n and refractivity, N are related by the equation:

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

IV. METHODS

The meteorological data such as temperature, relative humidity and pressure values collected from January 2014 - December 2016 were used to calculate the radio refractivity value using the refractivity expression in equations 1-3 above to give twenty four (24) data point representing hourly radio refractivity variation for each day of the year. The water vapour pressure, e and the saturated vapour pressure, e_s was determined using the expression in equations 4 and 5, respectively. The hourly data for each day is averaged to give a data point for the day and the average were further taken to give the average daily variation of tropospheric radio refractivity over all the years investigated. The daily data average was taken over the month to give a data point for each month overall the years which was used to determine the average seasonal variation.

A correlation between the tropospheric radio refractivity and the three meteorological parameters (relative humidity, temperature and pressure) was done using regression statistical analysis model from excel software. This was achieved by using the regression model on the data analysis tool, taking the measured radio refractivity value as the input Y range and all the three meteorological parameters values as the input X range, then request the software to compute the correlation coefficients, R and the coefficient of determination, R^2 by closing the dialogue box. The correlation coefficients, R

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explains that the combination of the independent variables (temperature, relative humidity and pressure) gives the result of the dependent variable (estimated refractivity), the coefficient of determination, R^2 shows the output of regression analysis and the percentage of coefficient of determination, R^2 shows the percentage contribution of the independent variables. The correlations results were determined and the comparison between the actual (measured) and estimated tropospheric radio refractivity was plotted.

The analyses were all achieved using Microsoft excel and Matlab softwares.

V. RESULTS AND DISCUSSION

The results of the investigation are graphically presented in Fig. 1-6. The average day to day (hourly) variation of refractivity, relative humidity, temperature and pressure, respectively plotted against time for January 2014 – December 2016 is presented in Fig. 1. Fig. 1 shows that the parameters exhibit day – night cycles. The refractivity plot shows that the value of refractivity decreases steadily from the 00 hours to a minimum value of 375.0 N units at the 0600 hours local time. From which it increases steadily till it reaches a peak value of 380.3 N units at the 1400 hours local time, it then started decreasing uniformly to about 1900 hours local time reaching another minimum value of 377.5 N units. It thereafter rose steadily until 2300 hours local time, to complete the day's cycle.

From the visual inspection of the temperature and pressure plots, the variation of temperature and pressure respectively shows a pattern that follows the same pattern as that of refractivity. The only difference is between 1900 and 2300 hour local time. Temperature and pressure could not observe the increase showed on the refractivity between 1900 hour local time till the end of the day, rather they show decreased till the end of the day.

It could be seen from the relative humidity plot that relative humidity increased gradually from 00 hours local time until it reached its peak at 0600 hours local time with a value of 82%. It thereafter decreased steadily before reaching its minimum at 1300 hours local time with a value of 64%. From the minimum value, it rose until it reached its night-time level.

From the results we observed that temperature and pressure are in phase with refractivity while relative humidity is in anti-phase with refractivity as well as temperature and pressure. However, the results of pressure and temperature maintain the ideal gas relation where pressure is proportional to temperature.

From the above analysis, we conclude that the diurnal variation of refractivity in Lagos is highly dependent on pressure and temperature with little contribution from relative humidity. The presence of Atlantic Ocean surrounding this area may be a good reason for high water content in the atmosphere.

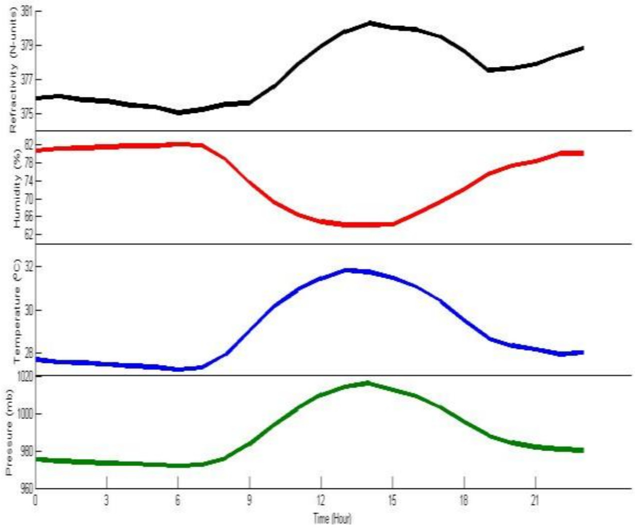

Figure 1: Average Hourly Variation of Refractivity (black), relative humidity (red), temperature (blue) and pressure (green) over Lagos

The mean monthly variation of radio refractivity presented in Fig. 2 shows high values of refractivity in the months of March to October and the period coincided with the rainy season period in Lagos. The minimum and maximum value of refractivity was observed in the months of January and March, respectively. The value of refractivity increases from a minimum of about 369.9 N-units in January to a maximum at about 381.4 N-units in March. The noticeable drop in August may be attributed to the period of scanty of rainfall during the rainy season popularly known as August break.

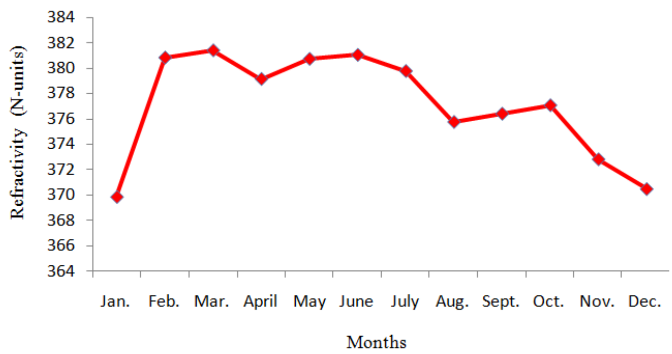

Figure 2: Average Monthly Variation of Surface Refractivity over Lagos

The average seasonal variation of refractivity, relative humidity, temperature and pressure plotted against time for January 2014– December 2016 is presented in Fig. 3 and Fig.

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4. Fig. 3 shows the average seasonal variation of refractivity, relative humidity, temperature and pressure over Lagos for dry season. The refractivity plot shows a steady decrease from early hours of the day until it reached a minimum at about 371 N-units around 0700 hours local time. It thereafter increases from then until it peaked at about 377 N-units around 1400 hours local time from which it dropped till it reached another minimum at about 373 N units around 2000 hours local time. It then rose till the end of the day. The variation of relative humidity, temperature and pressure can be used to understand the refractivity variation in Lagos during the dry season.

The temperature was lowest around 0700 hour's local time. It thereafter increases steadily from then to maximum around 1300 hours local time from which it dropped for the rest of the day. The variation of humidity followed opposite trend with highest and lowest values around 0700 hours' local time and 1300 hours local time, respectively. The pressure showed early hours decrease up to around 0600 hours local time and it steadily increased from then till around 1400 hours local time before it dropped till the end of the day.

Fig. 4 shows the average seasonal variation of refractivity, relative humidity, temperature and pressure over Lagos during rainy season. The refractivity plot shows a steady decrease from early hours of the day until it reached a minimum at about 377 N-units around 0600 hours local time. It thereafter increases from then until it peaked at about 382.5 N-units around 1600 hours local time from which it dropped till it reached another minimum at about 380 N units around 1900 hours local time. It then rose till the end of the day.

The temperature was lowest around 0600 hour's local time. It thereafter increases steadily from then to maximum around 1500 hours local time from which it dropped for the rest of the day. The variation of humidity followed opposite trend with highest and lowest values around 0600 hours local time and 1500 hours local time, respectively. The pressure showed early hours decrease up to around 0600 hours local time and it steadily increased from then till around 1500 hours local time before it dropped till the end of the day.

However, the combination of these meteorological parameters can be used to explain the refractivity variation at Lagos during the dry and rainy seasons. The consideration of the pressure and temperature variations as depicted in Fig. 3 and Fig. 4 show almost a synchronous pattern with refractivity except with slight differences around 1900 and 2000 hours local time, respectively till the end of the day. These discrepancies are attributed to the contribution of the variation of humidity. The percentage contribution of the N_{wet} and N_{dry} is 32% and 68%, respectively. It means that the N_{dry} is twice times that of N_{wet}. This shows that the high percentaged parameter suggested the most meteorological parameter that influences variation of refractivity over Lagos.

Thus, from the above analysis, we conclude that refractivity in Lagos during rainy and dry seasons is highly dependent on pressure and temperature with little contribution from relative humidity. This result is in line with the results of Bawa *et al.* (2015.).

The results also revealed that the highest value of refractivity in the dry and rainy season was 377 N units and 382 N units, respectively. This result is also in line with the results of Adeyemi and Adedayo (2005); Akpootu and Iliyasu (2017).

The highest value of refractivity during rainy and dry season shows a little difference. We also concluded that the presence of water vapour in the air during the dry season can be attributed to evaporation from the Atlantic Ocean that covers the entire area.

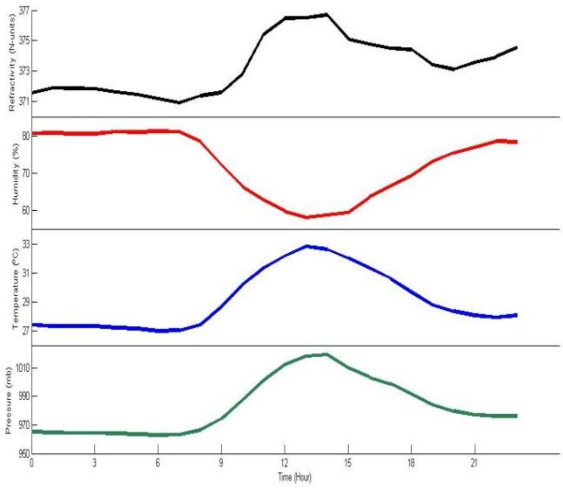

Figure 3: Average Seasonal Variation of Refractivity, Relative humidity, Temperature, Pressure over Lagos for Dry Season

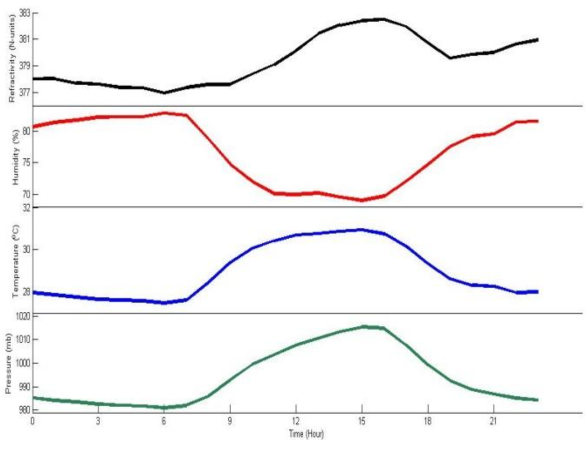

Figure 4: Average Seasonal Variation of Refractivity, Relative humidity, Temperature, Pressure over Lagos for Rainy Season

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The contour plot in Fig. 5 presents the summary of the average hourly and seasonal variations of surface refractivity. It can be clearly seen from the plot that the high values of refractivity occur between March and October which shows the period of rainy season. The highest refractivity value was identified to be in the month of March as shown on the plot. The period of scanty of rainfall during the raining season that occurs in August called August break was also identified.

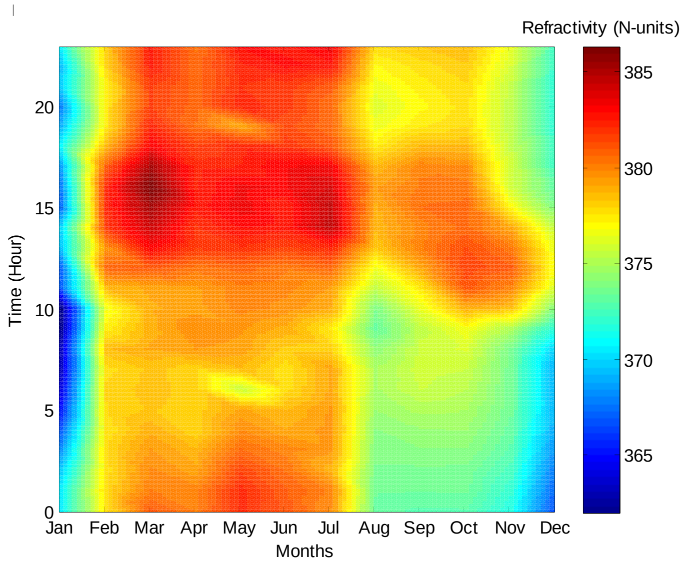

Figure 5: Average Hourly and Seasonal Variations of Surface Refractivity over Lagos

The regression statistical analysis was used for the correlation between refractivity and the three meteorological parameters (temperature, relative humidity and pressure). This was done in order to estimate the extent to which these three parameters correlate with the refractivity and to predict the value of refractivity based on the value of the three parameters.

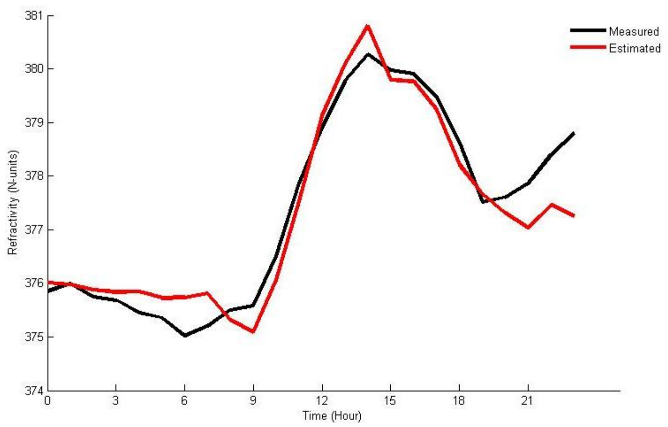

Figure 6: Correlation of Measured and Estimated Refractivity Values over Lagos

The results from the regression analysis show that the value of correlation coefficient, R and coefficient of determination R^2, respectively determined was 0.956 and 0.914. The percentage contribution from R^2 shows that the parameters contributed 91.4% of the refractivity variation at Lagos. This shows that the relationship of the meteorological parameters in generating the refractivity at Lagos is strongly positively correlated.

Fig. 6 presents the comparison between the measured (actual) refractivity value and the estimated value. It can be seen from the plot that the actual refractivity and estimated refractivity values followed the same trend. The deviation or absolute value determined was 0.10 and percentage error is given as 0.03.

VI. CONCLUSION

The analysis of the results revealed that the surface radio refractivity shows little significant difference during rainy and dry seasons. The high value of refractivity during the dry season may be due to the presence of water vapour in the air that causes evaporation from the Atlantic Ocean that covers the area. The variation of refractivity depended on the high percentage value of the dry term of refractivity which is a function of pressure. The results of statistical regression analysis gave a strong positive correlation between refractivity and the three meteorological parameters. This implication is that the regression statistical model can be used to estimate the variation of refractivity in Lagos, Nigeria using available data from the three meteorological parameters such as temperature, humidity and pressure.

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