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Full Length Research

Variations in the Tropospheric Surface Refractivity over Makurdi, Nigeria

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This work studied the hourly and seasonal variations in the tropospheric surface refractivity (N) over Makurdi (7.74°N, 8.51°E), Nigeria. The results showed among other things that the tropospheric surface refractivity was prevalent between February and October. The rainy season refractivity occurred between the hours of 0800h LT and 0400h LT, while in the dry season, it occurred between 00and 1200h LT. The dry term contributions to N were 68.3% and 77.2% in rainy and dry seasons respectively. Thus, the tropospheric surface refractivity over Makurdi, Nigeria is driven by the dry term which is a function of pressure.

Key words: Temperature, barometric Pressure, relative humidity, tropospheric surface refractivity, saturation vapor pressure.

1.0 Introduction

Line - of - sight (LOS) microwave links are prone to severe fading due to refraction of the transmitted waves along the propagation path. Hence, refractive fading can significantly impair service on terrestrial LOS microwave transmission. Microwave propagation through the troposphere is affected by varieties of natural phenomena caused by some meteorological parameters, such as pressure, temperature and relative humidity at Ultra high frequencies (UHF) and microwave frequencies (Adeyemi and Emmanuel, 2011).These effects are analyzed from the study of radio refractive index derived from these parameters. These parameters vary considerably diurnally and seasonally in the tropics .Therefore, the knowledge of the refractivity is essential in order to design reliable and efficient radio communication (terrestrial and satellite) systems. Thus, the refractive index of the troposphere is very important for estimating the performance of terrestrial radio links.

At frequencies above 30MHz, the ionosphere does not normally reflect radio energy, and changes in the refractive index of the atmosphere affect radio frequencies above 30MHz, although, these effects become significant at frequencies greater than about 100MHz in the lower atmosphere (Ayantunji *et al*., 2011). Hence, the refractive index, n of the troposphere is of major concern in the propagation of radio waves at these frequencies. The characteristics of the seasonal variation in fading and its dependence on meteorological parameters provide the way to improve transmission performance by tailoring the transmission equipment design and usage to the amount of fading expected at a given location and time of the year.

For dry air, n can be deduced from (Bayong Tjasyono and Djakawinata, 1999):

$$(n-1) \times 10^6 = K_1 \frac{P}{T} \quad (1)$$

where K_1 is a constant.

The value of the atmospheric refractive index, n is slightly greater than unity (about 1.0003). Therefore, atmospheric refractive index, n is measured by a quantity called the radio refractivity, N., which is related to n by (ITU – R, 2003; Adediji and Ajewole, 2008):

$$n = 1 + N \times 10^6 \quad (2)$$

Equation (2) is the same as the term on the left side of equation (1). For water vapour, N is given by (Bayong and Djakawinata, 1999) as:

$$N = (n-1) \times 10^6 = \frac{K_3\ e}{T^2} - \frac{K_3\ e}{T} \quad (3)$$

P is the barometric pressure in millibars, T is the absolute temperature in Kelvin and e is the partial pressure of water vapor in millibars.

For microwaves with wavelengths greater than 2cm or frequencies less than 15GHz, the constants K_1, K_2 and K_3 have values 77.6K/mb; 5.6K/mb and 3.75 x10^5 K^2/mb respectively (Bean and Dutton, 1968). Combining equations (1) and (3) and substituting the respective values of K, N for moist air can be computed from the equation:

$$N = 77.6\frac{P}{T} - 5.6\frac{e}{T} + 3.75 \times 10^5 \frac{e}{T} \quad (4)$$

At all atmospheric temperatures, the second term of equation (4) will be much smaller than the others (Bayong Tjasyono and Djakawinata, 1999). Hence, for practical work in radio meteorology, equation (4) can be rewritten and employed for computing N as (Hall, 1979):

$$N = 77.6\frac{P}{T} + 3.75 \times 10^5 \frac{e}{T} \quad (5)$$

Or $$N = \frac{77.6}{T}\left(P + 4810\frac{e}{T}\right) \quad (6)$$

The first term of equation (5) is called the dry term, while the second term, which is a function of vapor pressure and (or relative humidity) is referred to as the wet term. It has been observed that N_{wet} is mainly responsible for the variability in N within the troposphere (Adeyemi and Emmanuel, 2011). Equations (5) and (6) may be used for radio frequencies up to 100GHz (Adediji and Ajewole, 2008; Adeyemi and Emmanuel, 2011). The error associated with the use of this expression is less than 0.5 %(ITU- R, 2003).

The water vapor pressure can be obtained using (Adeyemi and Emmanuel, 2011):

$$e = \frac{He_s}{100} \quad (7)$$

For Radiosond relative humidity,

$$e = He_s \quad (8)$$

Where H is the relative humidity (%), e_s is the saturated vapor pressure (hpa) at the temperature t in (°C). The e_s can be determined using Clausius Clapeyron equation:

$$e_s\,(\mathrm{T}) = \mathrm{A}e^{-\mathrm{B}/\mathrm{t}} \quad (9)$$

Where the constant A is 2.53 x 10^8 kPa and B is the 5.4 x 10^3 K over water. Over ice, A and B are respectively 3.41 x 10^9 kPa and 6.13 x 10^3. Hence, using the relevant constants,e_s , which is the maximum (or saturated) vapor pressure at a given air temperature t (°C) may be obtained (Ayantunji *et al*., 2011):

$$e_s = 6.11exp\left[\frac{17.502t}{(t+240.97)}\right] \quad (10)$$

Hence equation (7) becomes

$$e_s = \frac{H \times 6.1121\, exp\left[\frac{17.502t}{(t+240.97)}\right]}{100} \quad (11)$$

Some research works on radio refractivity have been carried out in Nigeria. The dependence of surface refractivity on atmospheric parameters such as pressure, relative humidity and temperature in Jos, Nigeria was investigated by Agbo (2011); and he observed that both hourly and diurnal surface refractivity are highly dependent on relative humidity, and that the surface refractivity in Jos has a negative correlation relationship with temperature. Furthermore, dry season refractivity has higher variability than the rainy season refractivity.

The empirical evaluation of wet term refractivity in Nigeria carried out by Agunlejika and Raji (2010) revealed that southern stations in Nigeria have higher refractivity values than the northern stations. Hence, Ekpe *et al*., (2010) who worked on the variation of tropospheric surface refractivity at Nsukka in the south east, Nigeria observed that the surface refractivity is generally higher in the wet season than in the dry season. However, they found that a change in temperature influenced refractivity much more than a change in either relative humidity or pressure.

On the other hand, Ayantunji *et al*., (2011), who studied the diurnal and seasonal variations of surface refractivity over Nigeria, using four years in-situ meteorological parameter data from eight stations over Nigeria, including Makurdi, observed that the surface refractivity has higher values during the rainy season than during the dry season in all the locations.

Adeyemi and Emmanuel (2011) worked on monitoring tropospheric radio refractivity over Nigeria using Satellite Application Facility on Climate Monitoring (CM SAF) data derived from National Oceanic and Atmospheric Administration (NOAA) – 15, 16 and 18 satellites. Their results showed, among other things that variations in each region and at different atmospheric levels are influenced by the north – south movement of the Intertropical discontinuity (ITD). This was supported by the results of Adediji and Ajewole, (2008), which showed that the higher values of N during the rainy season were due to high air humidity due to the influence of Intertropical convergence zone (ITCZ) carrying high moisture laden air.

Adediji and Ajewole, (2008) in studying the vertical profile of radio refractivity gradient in Akure, Nigeria, noted that one reason for multipath of electromagnetic wave is the bending due to variation in the refractive index distribution along the layers of the atmosphere.

Studies by Adeyemi and Adedayo, (2005) on the atmospheric refractivity and water vapor density at Oshodi and Kano, Nigeria showed that atmospheric refractivity is generally high during the rainy season at all levels of the atmosphere , while its value fall during the harmattan period .

Makurdi is the capital of Benue state located in the north-central of Nigeria. It lies on the south bank of the Benue River. It is located at latitude 7.74°N, longitude 8.51°E at an elevation of about 104 m above sea level. The temperatures are generally very high during the day, particularly in March and April. Along the river valleys, these high temperatures coupled with high relative humilities produce very uncomfortable weather conditions. Makurdi records average maximum and minimum daily temperature of 35°C and 21°C in dry season; and 37°C and 16°C in wet season respectively. Hence, this work aims at finding the contributions this high temperature conditions and its attendant high relative humidity on the refractivity of radio waves in the area. We therefore, investigate the hourly and seasonal variation of tropospheric surface refractivity in Makurdi, Nigeria using 2007- 2009 data from Campbell automatic weather (University of Agriculture, Makurdi) station, with telemetry capability. This station has discrete sensors with the capability of sending all the data to a single server. The integration time for the data was five minutes.

2.0 Methodology

Hourly mean values of the parameters were obtained by averaging the five minutes recorded data. Similarly, the mean daily values were obtained by averaging the hourly data, which were in turn averaged to get the mean monthly values of the data. Equation (11) was used to compute the values of the saturated vapor pressure, e_s . These e_s values were then substituted into equation (7) to obtain the values of the water vapor pressure, e. The values of e, P and T were then employed into equation (6) to obtain the refractivity values for the station.

3.0 Results and Discussions

Figures 1 and 2 present respectively the variations in the rainy season hourly surface refractivity and the corresponding contributions of the wet and dry terms in the hourly surface refractivity over Makurdi, Nigeria. It could be observed from the Figure 1 that the refractivity (N) decreased uniformly from 00h LT to 0700hLT and uniformly increased to a value of 393.4N-units at 1400hLT. However, there was a small decrease from 1400 – 1500h LT. The value of N then increased to the peak value of 394.2N-units at 1700h LT, after which it dropped sharply until 2300h LT. Hence, this decrease in N continued till the minimum of 358.9N-unit at 0700hLT. Table 1 presents the maximum and minimum values of the hourly surface refractivity (including that due to dry and wet terms) obtained in the rainy season

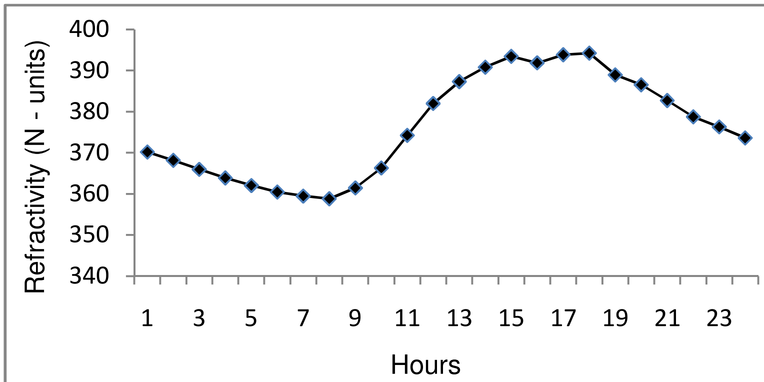

Fig. 1: The Variation in hourly surface refractivity in the rainy season over Makurdi, Nigeria

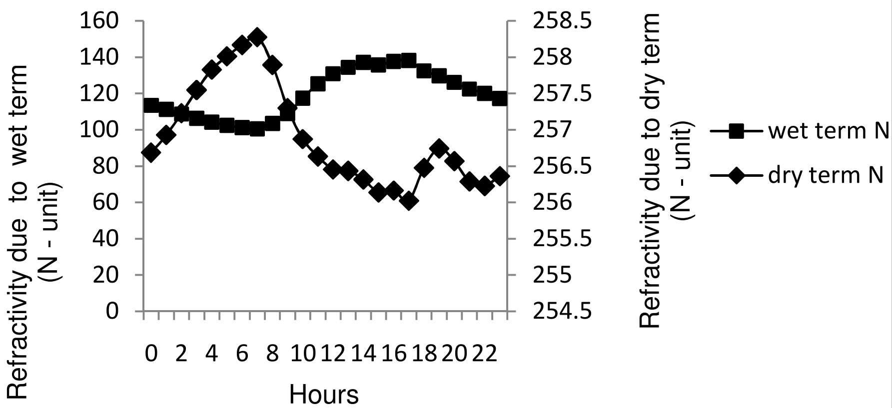

Fig 2: The contributions of the wet and dry terms in the hourly surface refractivity in rainy season over Makurdi, Nigeria

Table 1: Maximum and Minimum Values of the Average Hourly Surface Refractivity in the Rainy Season over Makurdi, Nigeria.

Refractivity (N- unit)	Maximum Values	Minimum values	Time (h LT) T_{max}	T_{min}
Rainy Season	394.2	358.9	1700	0700
Wet-term contribution	138.2	103.6	1700	0800
Dry-term contribution	258.3	256.0	0700	1700

For the wet term, the highest refractivity of 138.2 N-units was observed at 0500h LT, after which, it decreased steadily to the lowest value of 100.6 N-units at 0700h LT. It is interesting to notice the similarities between the profiles of the wet term contribution (Fig.2) and that of the wet season refractivity (Fig. 1): Both curves have the same trend in variation. In addition, it could be observed that the decrease in refractivity between the hours of 1400 and 1700h LT in rainy season (Fig. 1) corresponds to that in the wet term (Fig. 2). This could be attributed to the fact that the wet term is a function of moisture level or relative humidity, which is mostly high during the rainy season.

On the other hand, the contribution due to the dry term for rainy season had two peaks, the first peak of 258.3 N-unit occurred at 0700h LT, while the second peak of 256.7N-units occurred at 0700h LT (i.e. 12 hours interval). The lowest value, 256.0N-unit, was obtained at 1700h LT. The pattern on the rainy season dry term contribution is not uniform as in the corresponding wet term.

It is important to note that although the pattern of the wet term contribution is similar to that of the overall rainy season profile, the dry term gave the highest contribution of 68.3%, while the wet term contributed 31.7% of the total rainy season hourly refractivity. Thus, the rainy season hourly surface refractivity over Makurdi, Nigeria is driven by the dry term.

The results of the dry season hourly refractivity and the corresponding contributions of the wet and dry terms in the hourly surface refractivity over Makurdi, Nigeria are given in Figures 3 and 4 respectively.

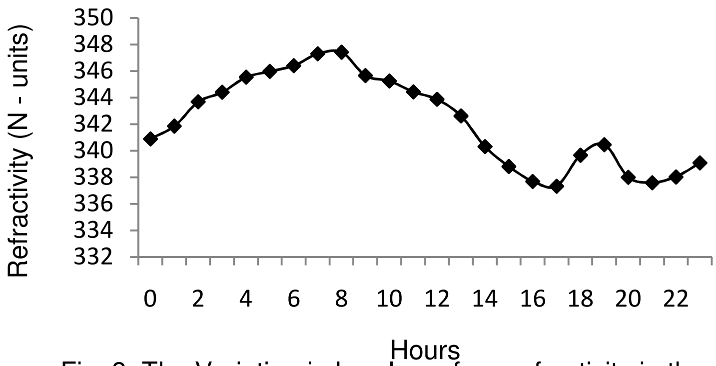

Fig. 3: The Variation in hourly surface refractivity in the dry season over Makurdi, Nigeria.

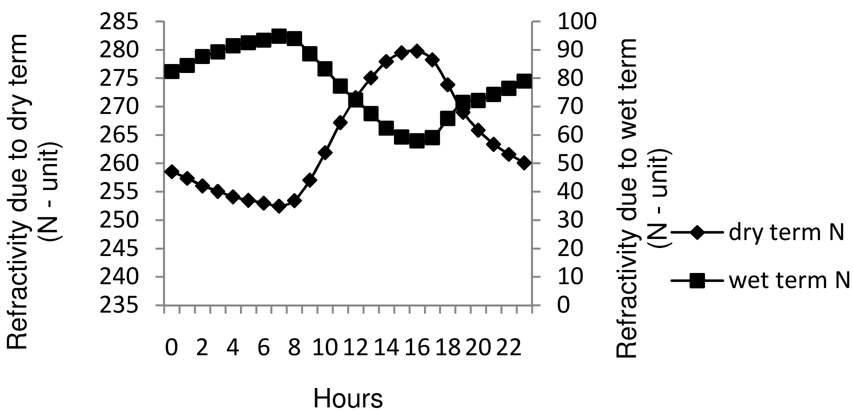

Fig 4: The contributions of the wet and dry terms in the hourly surface refractivity in dry season over Makurdi, Nigeria

From Fig. 3, the hourly N values increased uniformly from 340.9 N-units at 00 to 347.4 at 0800h LT and then decreased gradually to the least value of 337.3 N-units; after which it increased to the second peak of 340.5 N-units and decreased to 337.6 N-units and increased again to 339.1 at 2300h LT.

Observations show that the pattern in the variation of this dry season N is similar to that observed in the dry term curve of the rainy season N (Fig. 2), with the corresponding large and small peaks at 0700 and 1900h LT respectively with the least N occurring at 1700h LT in each case. This could be because in both cases, the N is a function of the dry term which is pressure.

Hence in considering the contributions of the dry and wet term on the dry season refractivity (Fig.4), it is observed that N in both cases had uniform pattern of variation. For dry term contribution, N decreased uniformly from 00h LT (258.5 N-units) to the least value of 252.5 at 0800h LT and then increased uniformly to the peak value of 279.8 N-units at 1600h LT before it gradually decreased again to 260.1 N-units at 2300h LT. On the other hand, the wet term curve exhibited a pattern opposite to that of the dry term. That is, N increased uniformly from 82.3N-unit at 00h LT to a maximum of 94.8N-unit at 0700h LTand then decreased to a minimum of 57N-unit at 1600h LT. It then increased again to 79.0N-unit at 2300h LT.

From Table 2, it can be observed that the in dry season, both peaks due to dry and wet term contributions occurred between 0700 and 0800 h LT, while the least N in both cases occurred around 1600h LT. Hence, in dry season, the highest refraction occurred between 0700 and 0800h LT and the least was obtained between 1600 and 1700h LT.

Table 2: Maximum and Minimum Values of the Average Hourly Surface Refractivity in the dry Season Over Makurdi, Nigeria.

Refractivity (N- unit)	Maximum Values	Minimum values	Time (h LT) T_{max}	T_{min}
dry Season	347.4	337.3	2000	1700
Wet-term contribution	94.8	57.9	0700	1600
Dry-term contribution	279.8	253.5	0800	1600

Again in dry season, just as in rainy season, the contributions due to the dry term was more , about 77.2%, than that due to wet term which was about 22.8%. Hence the refractivity in Makurdi, depends on the contribution of the dry term which is pressure.

Considering the hourly refractivity curves of Fig.1 (for rainy season) and Fig. 3 for dry season, it could be observed that in the rainy season, radio signals could be refracted less between the hours of 2300 to 0800h LT, but could be refracted most between the hours of 1000to 2200h LT. On the other hand, during the dry season, the highest refractivity could be obtained between 0600 – 0900h LT while the least refractivity was obtained between 1300 and 1700h LT.

This result also implies that in the dry season, radio waves are refracted most between the hours of 00 and 1200h LT; and between the hours of 1300 and 2300h LT the refractivity is less. This could be due to the fact that between 0900 and 2300h LT, the dry terms (P and T) were high and the wet term R_H was low as could be observed in Figures 5 and 6, thus, the dependence of the hourly N on the dry term in Makurdi during the rainy and dry seasons.

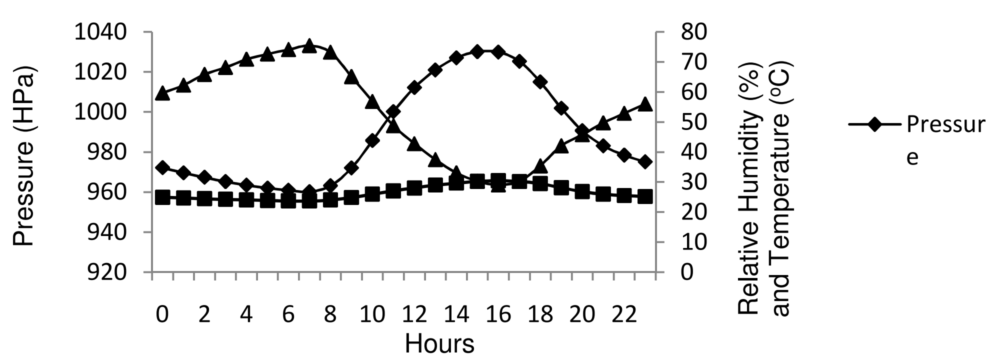

Fig. 5 : The average hourly Pressure, Temperature and Relative humidity in the Dry Season over Makurdi, Nigeria

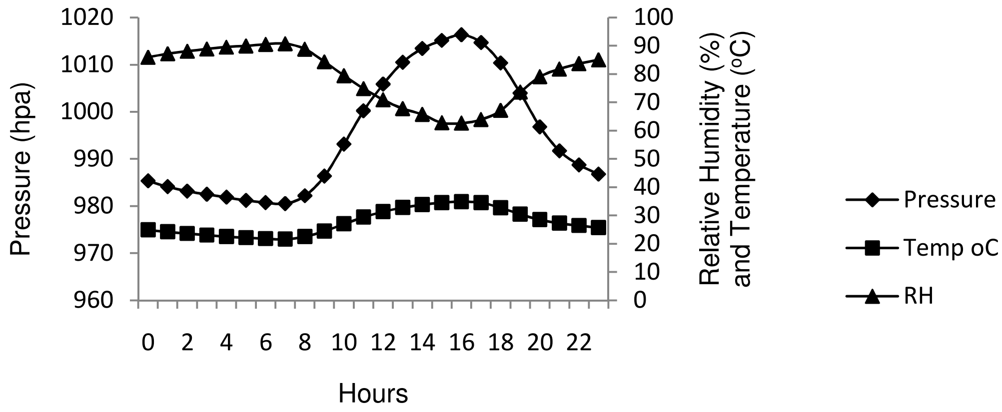

Fig. 6 : The average hourly Pressure, Temperature and Relative humidity in the Rainy Season over Makurdi, Nigeria

In considering the seasonal variations of the tropospheric surface refractivity, the data spanning from 1991 - 2010 were employed for a considerable climatic representation. Figures 7 and 8 present respectively, the seasonal variations of the tropospheric surface refractivity, N and the atmospheric parameters in Makurdi, Nigeria.

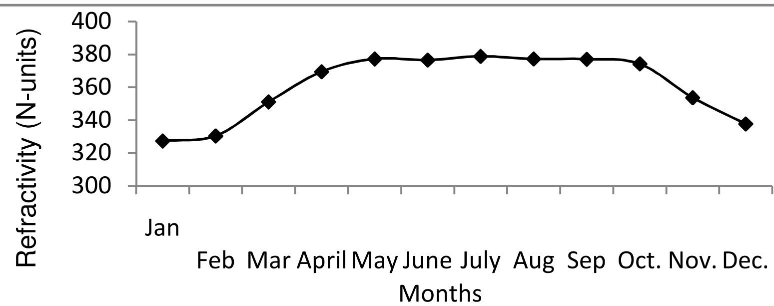

Fig .7: Monthly Variations of Tropospheric Refractivity over Makurdi, Nigeria

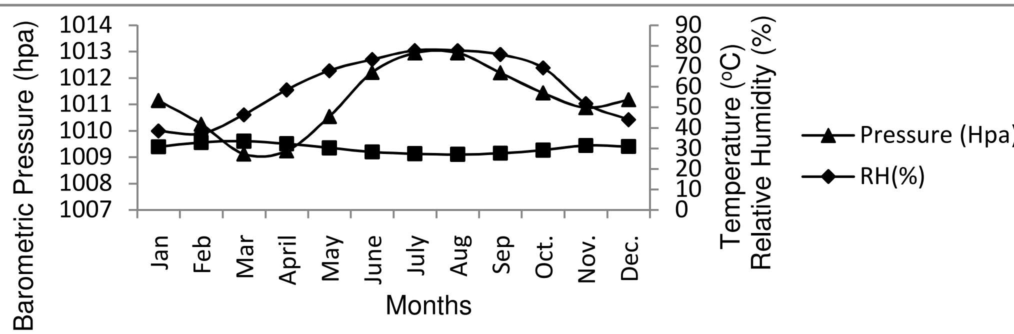

Fig. 8: Monthly Variations of the Barometric Pressur, Relative Humidity and Temperature over Makurdi, Nigeria.

Generally, it could be observed that N increased steadily from February to May. This is followed by a fairly constant increase to October, before a sharp decrease to December. The least value of 327.3N-units was observed in January, while the highest value of 378.8N-units occurred in the month of July. Thus, N was observed to be generally high during the rainy season (April to October). This could be due to high air humidity observed in Makurdi during the period (Fig. 8). Hence, in this period, Makurdi could have been under the influence of a large quantity of moisture laden tropical maritime air, resulting from continuous migration of inter tropical discontinuity with the sun. In December, N dropped because this is the period when the dry and dust laden north – east winds become dominant and the dry harmattern sets in, hence , the low N observed in January and February. On the other hand, between April and October, the whole city would have been subjected to widespread rainfall and increased cloud cover, N increased and became less variable. This is in line with the results of most refractivity behavior obtained in the tropics (Adeyemi and Emmanuel, 2011; Ayantunji *et al.*, 2011).

The rainy and dry seasons were grouped based on ITU specifications as given by Falodun and Kolawole, 2000. Hence, the rainy season consists of the months May – August, while the dry season is made up of November – February. March and April; September and October are grouped as transition months between the two seasons. Consequently, in this work, the 31.16% value of N was recorded for the dry season months, while 34.86% was recorded for the rainy season months.

Comparisons between the wet term (Fig 9) and the dry term (Fig. 10) of the seasonal variations in N reveal the following: The variations in N due to wet term followed the same patterns as the seasonal variations (Fig.7). This is irrespective of the fact that the dry term contribution to the overall seasonal N is greater (71.74%) than the corresponding wet term which had a 28.23% contribution. Hence, the overall refractivity in the area is driven by the dry term, whose main factor is the barometric pressure.

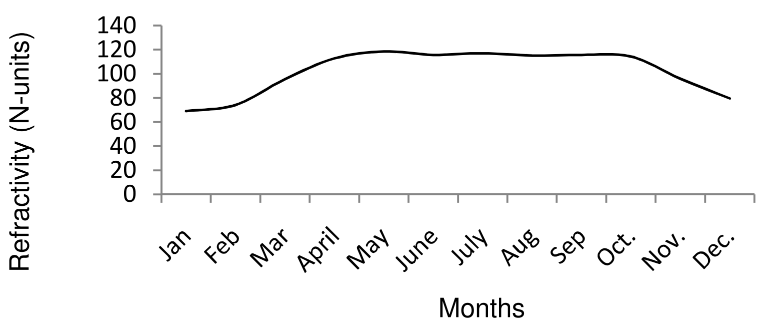

Fig .9:MonthlyVariations of Tropospheric Refractivity due to wet term.

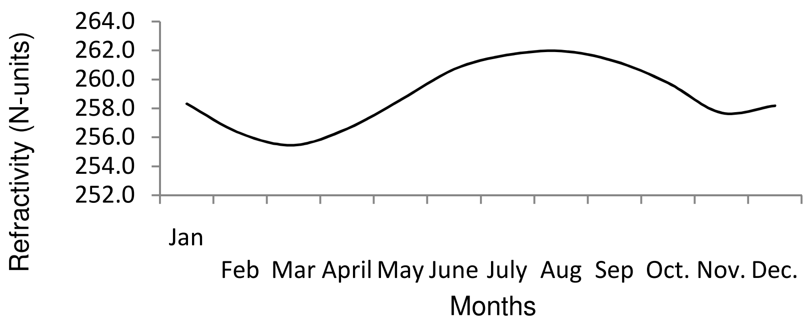

Fig .10: MonthlyVariations of Tropospheric Refractivity due to dry term.

The pattern followed by the dry term (Fig. 10) is somewhat cyclic in nature with the least N value of 255.5N-units in March and the peak value of 262N-units occurred in August. This is also the pattern followed by pressure (Fig. 8). This then confirms the fact that the dry term is a function of pressure. And the N due to the dry or pressure term was more during both seasons could be because the pressure seems cyclic in nature (as could be observed from Figs. 5, 6 and 8), irrespective of the season.

Comparing this work with that carried out by Ayantunji *et al*., 2011, in the same station, the following similarities could be observed in the seasonal variations of N: N increased steadily from February / March to May, followed by a fairly constant increase to October, before a sharp decrease to December. The least values were observed between December and January. Again, in both studies, N was observed to be generally high during the rainy season (April to October). In addition, the pattern of the variations obtained in hourly variations of N in the dry season is similar in both studies, especially in the existence of the double peaks in N, although at different hours in both studies. In both studies, it is established that the RH played a very crucial role in the rainy season N and on the wet term contributions to N.

However, in the diurnal investigations, some discrepancies are observed in the rainy season patterns. In this work, the maximum and minimum hourly N were obtained at 1700 and 0700h LT respectively, while 1200 and 1700h LT respectively were the time of occurrence for maximum and minimum of N as obtained by Ayantunji *et al*., (2011). Therefore, there is need for ascertaining the source of this discrepancy in the rainy season diurnal variations of N in these two results for the same station.

Conclusions

The following conclusions are made concerning the variations in the tropospheric surface refractivity, N in Makurdi, Nigeria :

- The N varies diurnally and seasonally. The N is prevalent between February and October. More refractivity (34.86%) occurred in the rainy season months than in the dry season months, when it amounted to about 31.6%. And in the rainy season, N increased between 0800 and 1600h LT and decreased between 1700 and 0700h LT. Although the wet term profile followed the same pattern as the overall rainy season profile, the contribution of the dry term in this season was larger (68.3%) than that due to wet term (31.7%).

- In the dry season, N increased between 00 and 1200h LT and decreased between 1300 and 2300h LT. The dry season variation in N had the same pattern as that due to the dry term contribution in the rainy season. Again, the dry term contribution in this dry season was more, about 77.2% than that (22.8%) due to the wet term. This implied that the dry term contribution which is a function of pressure was more than that of the wet term (a function of RH) in both seasons.

- Comparing this work with that of the Ayantunji *et al*., (2011), which was carried out in the same station, there is similarity in the results for the seasonal variations in N. But for the diurnal considerations, the periods for the maximum and minimum values of N were different in both results. Therefore, there is need for further verification of this discrepancy.

Acknowledgement

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