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Study of Average Hourly Variations of Radio Refractivity Variations across Some Selected Cities in Nigeria

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Abstract: *The results of the diurnal variation of refractivity based on measurement of atmospheric pressure, temperature and relative humidity made across some selected locations within Nigeria, Yola ($9^0$11' N, $12^0$30' E), Anyigba (7^0 45' N, $6^0$45' E), Lagos (6^0 27' N, $5^0$12' E), and Port-Harcourt (4^0 48'N, 7^0E), is presented in this study. The study utilized three years of meteorological data measured from January 2010 to December 2013 using Vantage Pro 2 automatic weather station installed at each location. The average hourly variations of refractivity in the dry season is largely as a result of the variations of the wet component (humidity) while the average daily variations of surface radio refractivity in the rainy season is as a result of both the variations of the dry (pressure) and wet (humidity) component of surface radio refractivity. It also observed that the values of surface radio refractivity showed seasonal variations with high value during rainy season and low values during dry season with an increase in the value of surface radio refractivity from minimum value of about 242N-units at Anyigba station to maximum value of about 384-N units at Lagos station. The diurnal variation of refractivity of the troposphere is a function of local meteorology as observed from results obtained from the study.*

Keywords: *Refractivity, Temperature, Atmospheric pressure, Relative Humidity*

I. Introduction

A radio waves propagating through the earth atmosphere will experience path bending due to inhomogeneous spatial distribution of the refractive index of air which causes adverse effects such as multipath fading and interference. These effect significantly impair radio communication, aero-space, environmental monitoring, disaster forecasting e.t.c.

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 in the troposphere. This region exerts a considerable influence on radio waves at frequencies above 30MHz, although this effect became significant only at frequencies greater than 100MHz especially in the lower atmosphere (Hall, 1979.).

The effect of meteorological variable of pressure, temperature, and relative humidity on radio wave propagation at UHF and microwaves frequencies are analyzed from the study radio refractive index derived from these three parameters (Bean and Dutton, 1966). Since these variables vary considerably daily and seasonally especially In the tropics, quantitative knowledge of refractivity variations is required in order to be able to design reliable and efficient radio communication (terrestrial and satellite) system. Although in radio propagation study, the troposphere is considered as a dielectric medium. The variations of the refractive index of the troposphere are small but nonetheless play an important role in radio wave propagation.

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 (Bean and Dutton, 1966; Segal, 1985). Due to the minute difference between the value of refractive index in the troposphere (about 1.0003) and that of free space (n = 1.0) it is more convenient to refer variations in refractive index in terms of a parameter called refractivity N (Thayer, 1974), which is defined as the measure of deviation of refractive index, n of air from unity which is scaled-up in parts per million to obtain more amenable figures. Thus, N is dimensionless quantity defined as measured in N units (Hughes, 1998).

Considering the importance of radio communication to this generation and the fact that there is lack or death of accurate data of meteorological parameters more especially in tropical region, this necessitate the call by International Telecommunication Union for meteorological data and many west African researchers has contributed to the development of this field, among the contributors to this field are; (Ayatunji, *et al*. 2011), (Okoro and Agbo,2012), (Adediji, *et al*. 2013), (Falodun and Ajewale, 2005), (Kolawole and Owonubi, 1982), (Kaissassou, et al. 2013), (Ali, et al. 2011), (Adeyemi and Kolawale, 1992), (Hughes, 1993), (Igwe and Adimula, 2009), (Owolabi , *et al*. 1970), (Kolawole, 1980), (Adediji and Ajewale, 2010).

This study presents the results of average daily and seasonal variations of surface radio refractivity derived from the computation of atmospheric pressure, temperature and relative humidity using recommendation ITU-R 453 (ITU, 2012).

II. Study Area

Nigeria lies between latitude 4^0N and 14^0N and longitude 2^0E and 15^0E respectively with a total area of 923,768 square kilometers. The countryis located between the Equator and the Tropic of Cancer. Thelatitude of Nigeriafalls within the tropical zone but the climatic conditions are not entirely tropical in nature. The climatic condition varies in most parts of the country, in the north the climatic condition is arid and to the south there is an equatorial type of climate. The weather condition can be generally characterized into wet season, from April to October; dry season, from November to March in the north and wet season, from March to October; dry season, from November to February in the south.

III. Relevant Theory

Electromagnetic waves propagating in the troposphere are refracted and scattered by variations in the radio refractive index *n*. Recall that the electromagnetic field of a plane wave propagating in a medium of constant refractive index, *n*, has a space, ***r***, and time, *t*, variation given by:

$$E(\boldsymbol{r}, t) = E_0 \exp[i(n\boldsymbol{k}_0 . \boldsymbol{r} - \omega t)] \quad 1$$

Where $\omega = 2\pi \times$ frequency and $\boldsymbol{k}0$ is a vector normal to the wave front with a magnitude equal to the free space wave number (= 2π/wavelength).

In the troposphere, the refractive index is not constant. At microwave frequencies, however, it varies slowly on the scale of a wavelength. In this case it is still possible to write:

$$E(\boldsymbol{r},t) \approx E_0 \exp[i(n(\boldsymbol{r})\boldsymbol{k}_0 . \boldsymbol{r} - \omega t)] \quad 2$$

Although the magnitude of $E(\boldsymbol{r},t)$ will in general vary with position. The value and variations of $n(\boldsymbol{r})$ are fundamental to understanding the way in which electromagnetic waves propagate through the troposphere.

The radio refractive index of the troposphere is due to the molecular constituents of the air, principally nitrogen, oxygen, carbon dioxide and water vapour. The value of *n* deviates from unity because of the polarisability of these molecules due to the incident electromagnetic field, and quantum mechanical molecular resonances. (Barclay, 1996).

According to ITU-R (2012), the atmospheric refractive index, *n*, can be computed by using:

$$\boldsymbol{N = \langle n - 1 \rangle \times 10^{-6}} \quad 3$$

Where *N* is radio refractivity expressed by

$$N = N_{dry} + N_{wet} = \frac{77.6}{T}\left(P + 4810\frac{e}{T}\right) \quad 4$$

with the 'dry term' of radio refractivity given by:

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

and the 'wet term' given by

$$\boldsymbol{N_{wet} = 3.732 \times 10^5 \frac{e}{T^2}} \;,$$

where: P is atmospheric pressure (hpa)

e is water vapor pressure (hpa) and

T is absolute temperature (K)

This expression may be used for all radio frequencies (for frequencies up to 100GHz; the error is less than 0.5%) for representative profiles of temperature, pressure and water vapour pressure (Babin et. al. 1997)

The water vapor pressure, e, can be calculated from relative humidity as

$$e = \frac{He_s}{100}$$

Where e_s is defined as

$$\boldsymbol{e_s = EF \cdot a \cdot exp\left\{\frac{\langle b - \frac{t}{d}\rangle \cdot t}{t + c}\right\}}$$

And:

$$\boldsymbol{EF_{water} = 1 + 10^{-4}[7.2P(0.00320 + 5.9 \cdot 10^{-7} \cdot t^2)]}$$

Where e_s is the water vapour partial pressure, t is temperature in Celsius, H is the humidity, and constants for water are *a* =6.1121 ,*b* =18.678, *c* =257.14 and *d* = 234.5(ITU-R, 2012).

IV. Methodology And Instrumentation

The indirect method of measuring refractivity was employed in this study. Surface values of pressure (hpa), Temperature (°C), and Relative humidity (%) were extracted from measurements made using Davis Vantage pro2 automatic weather station installed at the ground surface at Lagos (6^0 27' N, $5^0$12' E) Lagos State, Port-Harcourt (4^0 48'N, 7^0E) Rivers State, Anyigba (7^0 45' N, $6^0$45' E) Kogi State and Yola ($9^0$11' N, $12^0$30' E) Yola State. The weather stations have five minutes integration time.

Data collected from January 2011 to December 2013 were averaged over each hour to give twenty four data point representing diurnal variations for each day. The hourly data for each day is further averaged to give a data point for the day and average was taken over the month to give a data point for each month which was used to determine the monthly variations for each year. The corresponding months for each year of the three years under study were then averaged to give the average seasonal variations for the period under study. The data were used to compute the surface radio refractivity.

V. Figures

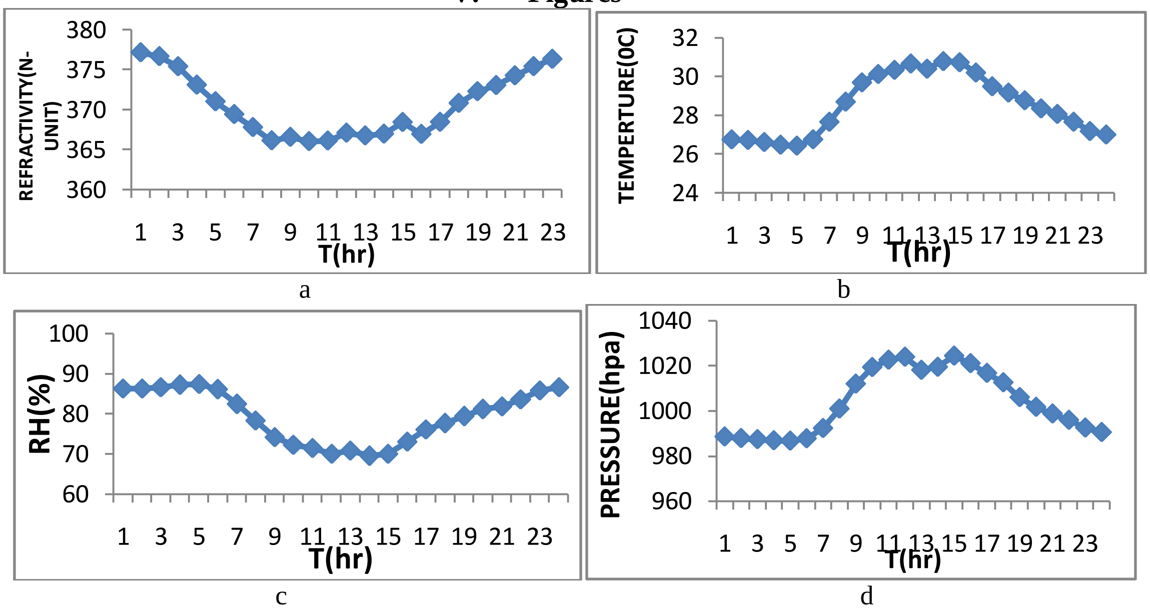


Fig. 1a To 1d Average Hourly Variations Of Surface Radio Refractivity, Temperature, Humidity And Pressure For Dry Season Over Lagos From 2011 To 2013

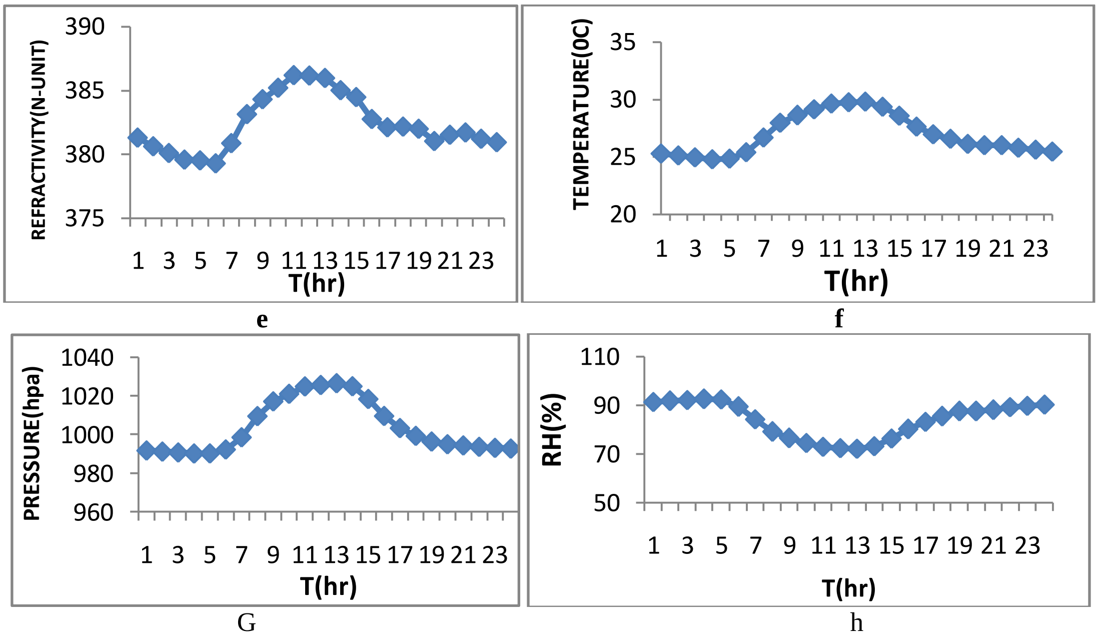


Fig. 1e To 1h Average Daily Variations Of Surface Radio Refractivity, Temperature, Humidity And Pressure For Rainy Season Over Lagos From 2011 To 2013

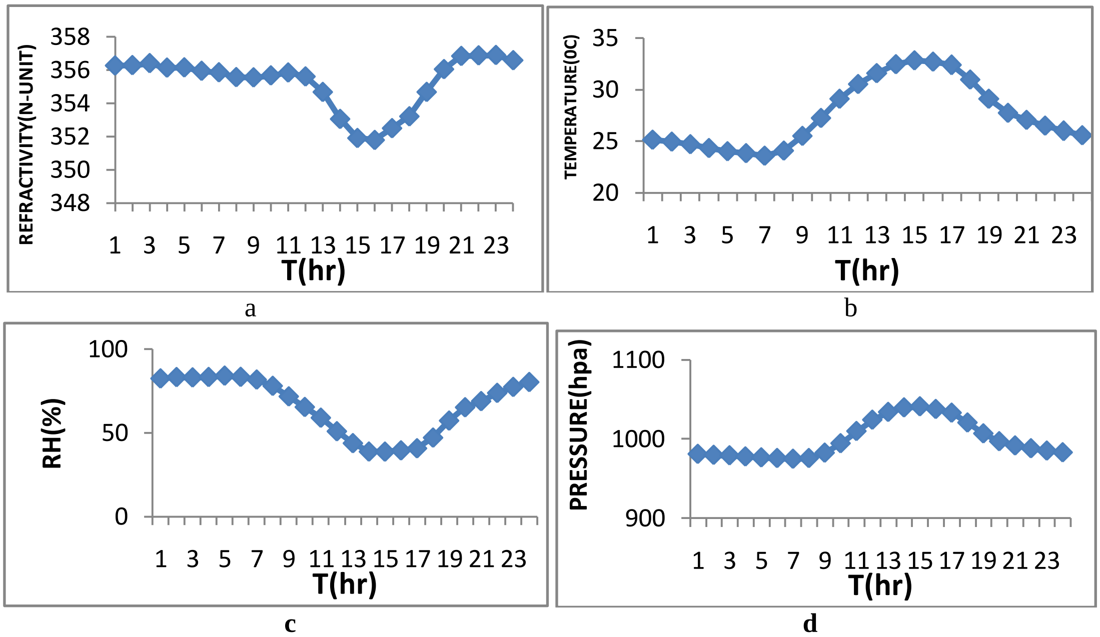


Fig. 2a To 2d AVERAGE DAILY VARIATIONS OF SURFACE RADIO REFRACTIVITY, TEMPERATURE, HUMIDITY AND PRESSURE FOR DRY SEASON OVER PORT-HARCOURT FROM 2011 TO 2013

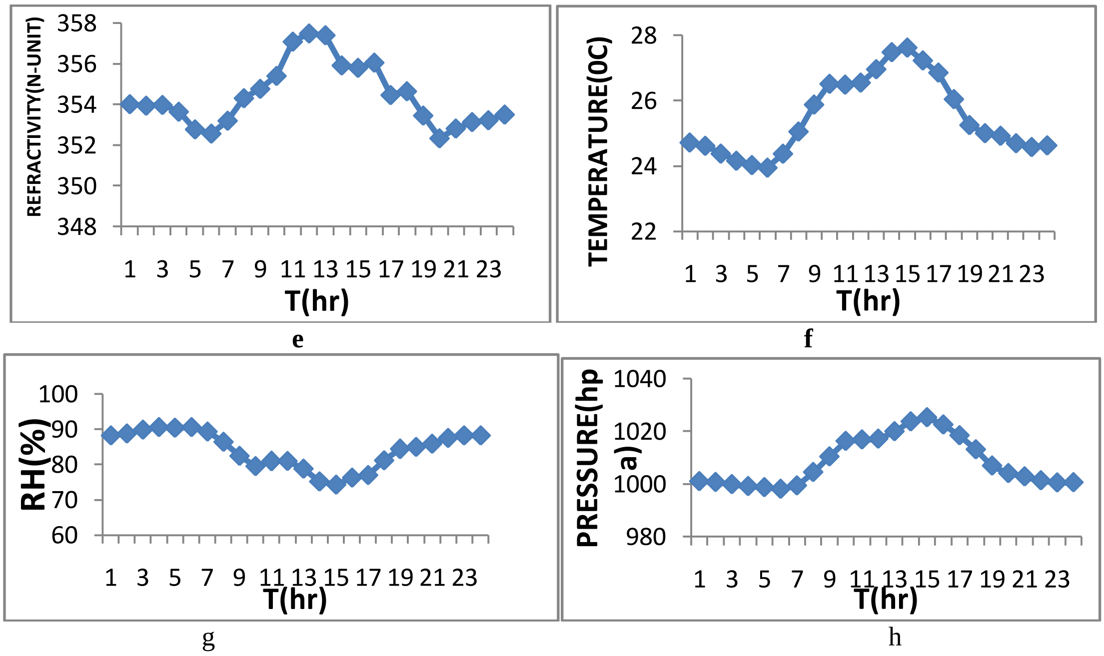
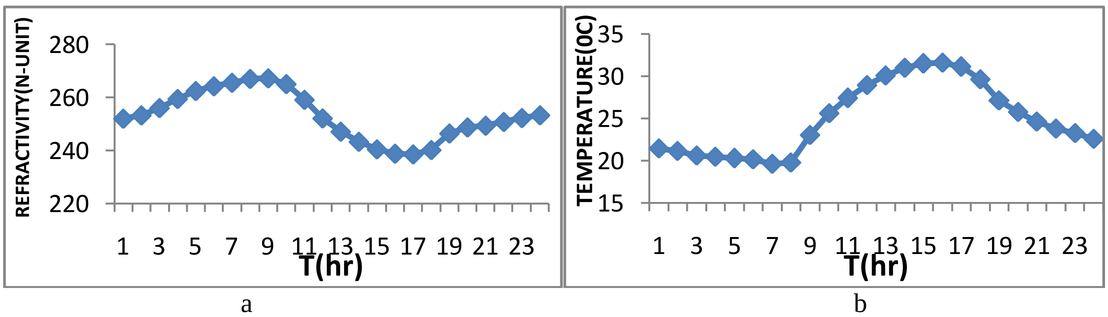
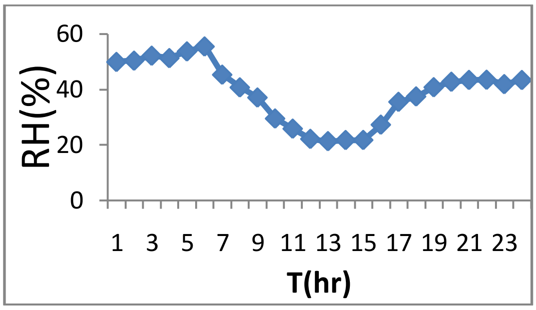


Fig. 2a To 2h Average Daily Variations Of Surface Radio Refractivity, Temperature, Humidity And Pressure For Rainy Season Over Port-Harcourt From 2011 To 2013





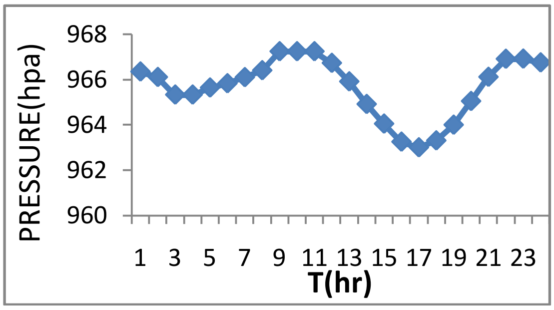


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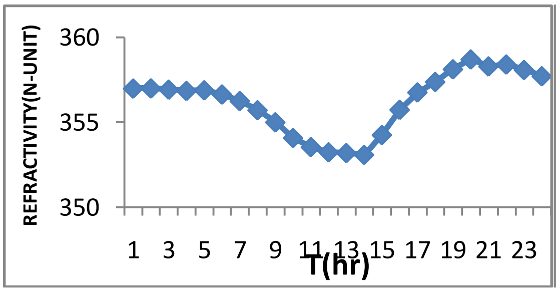
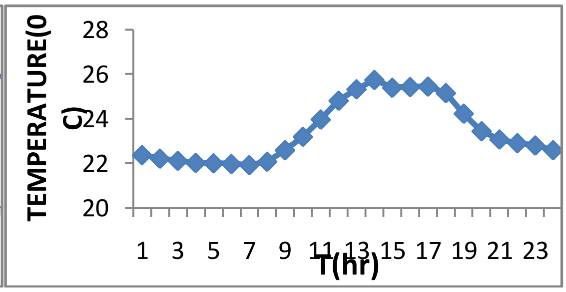
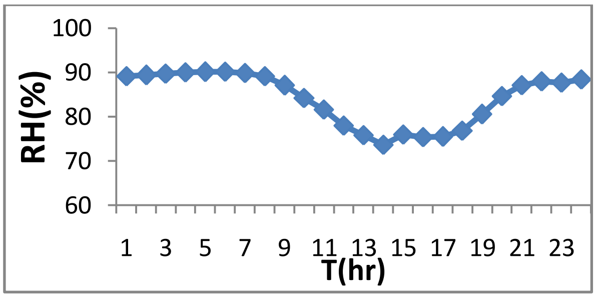
Fig. 3a To 3d Average Daily Variations Of Surface Radio Refractivity, Temperature, Humidity And Pressure For Dry Season Over Anyigba From 2011 To 2013





e **f**



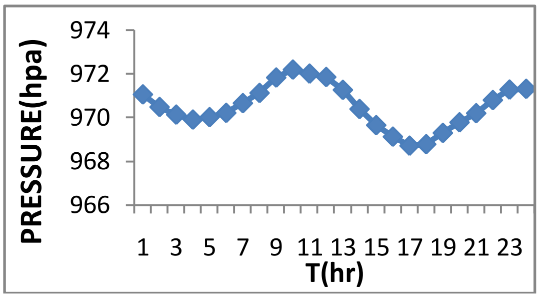


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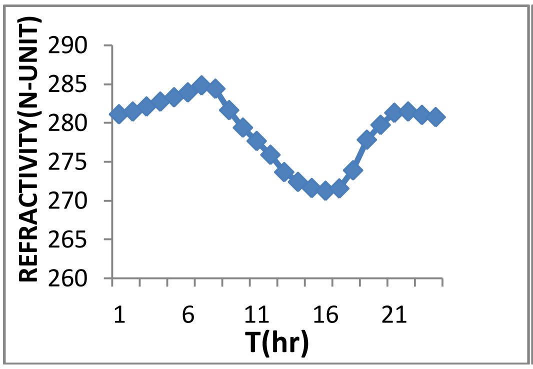
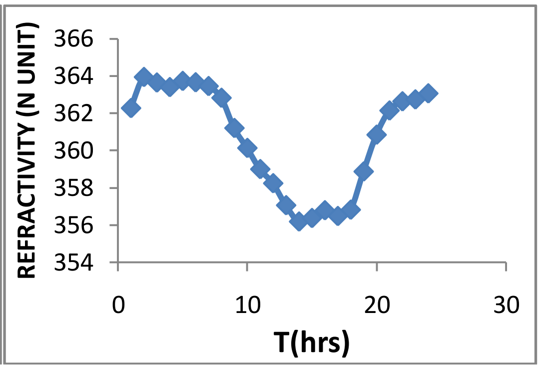
Fig. 3a To 3d Average Daily Variations Of Surface Radio Refractivity, Temperature, Humidity And Pressure For Rainy Season Over Anyigba From 2011 To 2013





a b

Fig. 4a And 4b Average Daily Variations Of Surface Radio Refractivity, For Dry And Rainy Season Over Yola From 2011 To 2013

VI. Results And Discussions

Average Hourly Variations Of Refractivity

Fig. 1a to Fig. 1h depictsthe average hourly variations of surface radio refractivity, Temperature, relative humidity, and pressure over Lagos for dry and rainy season. Fig. 1a represent the surface radio refractivity, shows strong dependence on the wet term (Humidity) of refractivity with high values in the morning and late in the evening and low values in the day time. This is attributed to the response of the earth to solar insolation which is the major force behind the weather condition observed. The solar insolation causes the temperature to be high and humidity low during the day. The highest value is 377 N-units and the lowest value is 366 N-units.

The average daily variations of surface refractivity over Lagos for rainy season is depicted in Fig. 1e, shows a maximum in the afternoon with a sudden rise pre-noon and sudden drop just at the noon. The maximum value is about 386 N-unit which occur between the 11:00hr local time and 12:00hr local time units and the lowest value is about 378 N-unit. To determine the major force driving the variations in rainy season, the signature of refractivity variation is compared with that of temperature, humidity, and pressure as depicted in Fig. 1f, 1g and 1h respectively. Fig. 1f depicts the variations of temperature over Lagos which shows low values in the morning and late evening with high values during the day. Fig. 1g depicts the variations of Humidity, these variations followed opposite trend as expected with high values in the morning and late evening. Fig. 1g depicts profile of Pressure; it showed a pattern that is almost synchronous with refractivity variations. Therefore the dry component (pressure) is major force driven diurnal variations of refractivity over Lagos during rainy season.

The diurnal variations of refractivity, temperature, relative humidity and pressure over Port-Harcourt for dry and rainy season is depicted in Fig. 2a to Fig. 2h respectively. Fig. 2a showed that the refractivity value in dry season is high in the early morning and late evening with maximum value of 356N-units and low during the day with minimum value of about 351 N-units between the 14:00hr LT and the 15:00hr LT. This is in agreement with what is expected when the refractivity variations is been driven by the wet term.

Fig. 2e depicts the diurnal variations of surface refractivity for rainy season, showed a sudden rise pre-noon and sudden drop post noon. The maximum value of 357 N-unit was observed around the noon. To understand the main force driven the variation in rainy season, Fig. 2f, 2g and 2h represent the profile of Temperature, Humidity and Pressure respectively. The Temperature profile showed lowest value around 6:00hr LT before gradually rise to a maximum value around 15:00hr LT. The variation of Humidity followed opposite trend as expected with high value around 6:00hr LT and minimum around 15:00hr LT.

The pressure profile showed a minimum value by 6:00LT and gradually increase to a first maximum value at noon before sudden increase to its peak value at 15:00 LT. The peak value of refractivity about this time as shown in Fig. 2e is attributed to the pressure variations (dry term) while sudden drop post noon is as a result of increase in temperature which lead to the decrease in Humidity and consequently the refractivity. Therefore, the variations refractivity during the rest of the day are attributed to the wet term.

The average daily variations of radio refractivity, temperature, relative humidity and pressure for rainy and dry seasons over Anyigba is depicted in Fig. 3a to Fig. 3h respective.

Fig. 3a depicts the refractivity variations for dry season over Anyigba, showed a sudden raised to reach a peak value of 267 N-unit around 8:00hr LT to 9:00hr LT and a gradual decreased to reached a minimum value of 238 N-unit around 16:00 LT and 17:00 LT. To show that the refractivity variations in dry season is likely driven by dry component. Fig. 3d depicts a pressure profile, shows a maximum at 9:00 LT and a minimum value at 17:00 LT. Therefore, the pressure profile shows almost a synchronous pattern of variations with refractivity variation depicted in Fig. 3a. This confirms that dry component (pressure) is the main driving force for refractivity variation at Anyigba for dry season.

Fig. 3e shows that in rainy season the refractivity is high (356N-units to 358N-units) in the early and late hours of the day. It gradually drops from 10:00hr local time and reach a minimum of 353 N-units around 13:00hr before gradually risen till the end of the day. Therefore, wet term is driven the refractivity variations in rainy season, while dry term is responsible for the variations in dry season.

The diurnal variations of refractivity, temperature, relative humidity and pressure for rainy and dry seasons over Yola is depicted in Fig. 4a and Fig. 4b respectively. The two profiles show low values in the day and high values in the morning and evening. The highest value for rainy season is about 363 N-units and the lowest value is 356 N-units while the highest value for dry season is 284 N-units and the lowest value is 271 N-units. The diurnal variations of refractivity over Yola showed a consistency with what is expected of humidity variations and therefore it is attributed to the wet term for both seasons.

The results obtained from the study shows that the average hourly variations of surface radio refractivity in dry season is majorly driven by the wet term (Humidity) at Lagos, Port-Harcourt and Yola stations, while, the dry component (pressure) is the major driving force the variations at Anyigba during the same season. The results also show that in rainy season, dry component (pressure) is the major force behind the variations at Lagos and Port-Harcourt while the wet term (Humidity) is the major cause of surface radio refractivity variations at Anyigba and Yola. This result also shows that the surface radio refractivity variations do not always depend on the wet term (humidity) only as reported by Adeyemi and Kolawole (1992) but is in agreement with the findings of Ayantunji et al (2011) which shows that the diurnal variation of refractivity depends on local meteorology as determine by the local topography.

VII. Conclusion

In-situ measurement of temperature, pressure and humidity were carried out at surface of Anyigba, Yola, Lagos and Port-Harcourt for a period of three years. The data from these stations were employed to determine the diurnal variation of radio refractivity at the stations under study using ITU-R Model. The major findings of this study are as follows:

- The average hourly variation of refractivity in the dry season is largely as a result of the variations of the wet (Humidity) component of refractivity while the average variations of refractivity in the rainy season is as a result of both the variations of the wet (Humidity) and dry (Pressure) components of refractivity.
- Hourly or Diurnal variation of refractivity depend on local meteorology as dictated by the topography.
- Refractivity values computed for the locations under study increases from about 242 N- units at Anyigba northern Nigeria to 384 N-units at Lagos southern Nigeria.

From the aforementioned findings, the following are some of the applications of this research work.

- The knowledge of meteorological parameters obtained in this study can be useful when planning frequency reuse in the locations.
- The surface radio refractivity data obtained in this study will provide radio engineers with adequate information relevant for the design of communication systems in the locations.
- It will serve as important parameter in determining the coverage and quality of VHF, UHF and microwave signals in the locations.

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