Indian Journal of Radio & Space Physics
Vol 43, December 2014, pp 355-361

Variability of meteorological factors on surface refractive index over Mowe, a coastal area in Nigeria

J A Falade[1,$,*], S O Adesanya[2] & G A Akinyemi[1]

[1]Department of Physical Sciences, Redeemer's University, Mowe, Nigeria
[2]Department of Mathematical Sciences, Redeemer's University, Mowe, Nigeria
[$]E-mail: falade_a@yahoo.com

Received 19 May 2014; revised received and accepted 11 December 2014

Radio climatology is an important factor in understanding radio wave propagation particularly in the troposphere where time varying properties due to weather conditions are prevalent. Therefore, the diurnal and seasonal variations of surface radio refractivity for Mowe (06°E, 52°N) via Lagos in South-West Nigeria are studied. Particular emphasis is laid on diurnal variations of the surface refractivity, which is high through the night and drops sharply just before sunrise and starts to pick up slightly around 14:00 to 15:00 hrs LT. It drops to minimum around 16:00 hrs LT before it increases again. The sinusoidal patterns of plots are obtained for temperature, relative humidity and refractivity. The patterns of the profile obtained are attributed to the oscillatory movement of inter-tropical discontinuity (ITD), which largely dictate the condition of weather and account for high rainfall in the coastal region where the study is undertaken. The results show that surface radio refractivity, generally, has higher value during the rainy season than dry season, which partly coincide with the harmattan period.

Keywords: Surface refractivity, Inter tropical discontinuity

PACS Nos: 78.20.Ci; 95.85.Bh; 92.60.Ry

1 Introduction

With the rapid expansion of wireless consumer products, understanding of the propagation phenomena is fundamental to the appropriate design of communication systems. Their effects on radio wave propagation produce random variations in the amplitude, phase, frequency, polarization, coherence bandwidth, delay spread, and propagation direction of the electromagnetic waves. Gradual variations in the refractive index result in bending of the paths taken by radio waves so that they can follow the curvature of the earth. Thus, the troposphere (an inhomogeneous medium) affects the propagation of ground waves and can promote communication over large ranges. Propagation data are statistically representative of propagation behaviour and associated conditions in both the troposphere in any location throughout the world. Unfortunately, in Nigeria, data are only available in few geographical locations while other locations are with staggered data that cannot vividly represent the statistical pattern of such location. As a consequence, the planning of broadcasting services for frequencies above 30 MHz are based on Recommendation 370 of the International Telecommunication Union (ITU)[1]. The data employed in obtaining these propagation curves and formulas are derived from measurements performed largely in the temperate region of the world and does not fit for radio network planning in Nigeria, a tropical region. Hence, an optimized planning requires an appropriate propagation data and curves obtained from measurements performed at different locations over Nigeria due to the climatic conditions at different times of the year. Changes in climatic conditions are products of meteorological factors in the locality both in terms of microscale and mesoscale. The coastal region requires special attention because of its close proximity to Atlantic Ocean and it experiences perennial inundation due to ocean surges and strong tidal waves, hence, dominated with intense weather activities. The temperature rarely exceeds 32°C but the humidity is very high, hence, copious rainfall is produced as a result of the condensation of water vapour in the rapid rising air. The annual rainfall is usually above 4000 mm. The tropospheric propagation data based on surface refractivity is now available in most parts of Nigeria but the values at different locations are widely varied. When the values are compared to the ones obtained by extrapolating radiosonde data points particularly in the vicinity of the ground, the variation is wider, which may result in anomalous propagation effects. Hence, there is need to study the differences in the refractivity measurements in the lower layer of the atmosphere especially in the first few meters above the ground. It is worth to monitor and discuss in terms of radio propagation because the statistics of radio refractivity is an important parameter for the estimation of path clearance and propagation associated effects, such as ducting on trans-horizon paths, surface reflection, multipath fading and distortion on terrestrial line-of-sight[2].

Studies of surface radio refractivity across the entire continent of Africa have been done but only in very few locations. High values of refractivity have been obtained at the coastal areas of the African continent while the inland areas have much lower values within the same climatic belt[3,4]. The results obtained in each zone are influenced by the characteristic topographical features and the prevailing atmospheric conditions, which are dependent on the seasonal northward and southward movement of the inter-tropical discontinuity (ITD). This largely dictates the weather patterns of Nigeria[5-7].

Though the contributions to radio science especially in the African region by past researchers are valuable, they could not still explore the diurnal and seasonal trends of surface refractivity at all locations with different climatic conditions. Nigeria, like the rest of West Africa and other tropical lands, has only two seasons. These are the dry season and the rainy season. The dry season is accompanied by a dust laden air mass from the Sahara Desert called the tropical continental (CT) air mass, locally known as harmattan. The rainy season is heavily influenced by an air mass originating from the South Atlantic Ocean called the tropical maritime (MT) air mass, locally known as the south-west trade wind. The wet season, lasts from April to October, with lower monthly temperatures and the wettest month being June. Also, the dry season, lasts from November to March, has an average mid-day temperatures higher than 38°C but relatively cool nights with temperatures dropping to a very low value, at times as low as about 12°C. Near the coast, the seasons are not sharply defined, average temperature rarely exceeds 32°C but humidity is very high and nights are hot.

1.1 Climate and Weather characteristics in Nigeria

According to Nigerian Meteorological Agency report[7], Nigeria lies wholly within the tropical zone with wide climatic variations in different parts of the country. The higher than normal ITD positions account for high rainfall in many cities across the country. The moist south-westerly winds from the South Atlantic Ocean, which is the source of moisture needed for rainfall and thunderstorms to occur, prevail over the country during the rainy season (April – October). In reverse, north-easterly winds, which raise and transport dust particles from the Sahara desert prevail all over the country during the harmattan period (November – March). The overall changes in temperature, rainfall and other meteorological parameters determine the changes in climate in the country each year. The 'August break' (little dry season) usually experienced in the southwest is less pronounced unlike in recent years[5,6].

The data available in the past could not explore well the diurnal trend of refractivity throughout Nigeria particularly in the coastal areas. Hence, the objective of this study is to use the propagation data obtained from the measurements made at a new Nigerian Environmental Climatic Observing Program (NECOP) station located at the Redemption Camp, Mowe (06°E, 52°N) (46 km away from Lagos) as shown in Fig. 1(a), to study the trend of diurnal, weekly, monthly and seasonal surface refractivity variation in coastal area of Nigeria.

2 Meteorological factors determining the index of refraction

The index of refraction is an additive quantity and can be calculated from[8-10]

$$\boldsymbol{N} = 77.6\,\boldsymbol{P}/\boldsymbol{T} + 3.75\times10^{5}\,\boldsymbol{e}/\boldsymbol{T}^{2} \qquad \ldots(1)$$

This is a generally accepted relationship for the dependence of atmospheric refractivity within the range of pressure $\boldsymbol{P}$ (mb), temperature $\boldsymbol{T}$ (K) and the water vapour pressure (mb) encountered in the tropics. According to Hall[8] and ITU[1], the terms 77.6P/T and 3.75×10^{5} $\boldsymbol{e}/\boldsymbol{T}^{2}$ are sometimes referred to as $\boldsymbol{N_{dry}}$ and $\boldsymbol{N_{wet}}$ respectively. The refractivity is derived from the Debye formula for the polarisability of polar and non-polar molecules. The first (dry) term is due principally to the non-polar nitrogen and oxygen molecules while the second (wet) term is from the polar water vapour molecules. The maximum saturated vapour pressure, $\boldsymbol{e_S}$, at the air temperature $\boldsymbol{t}$°$\boldsymbol{C}$ is[8]:

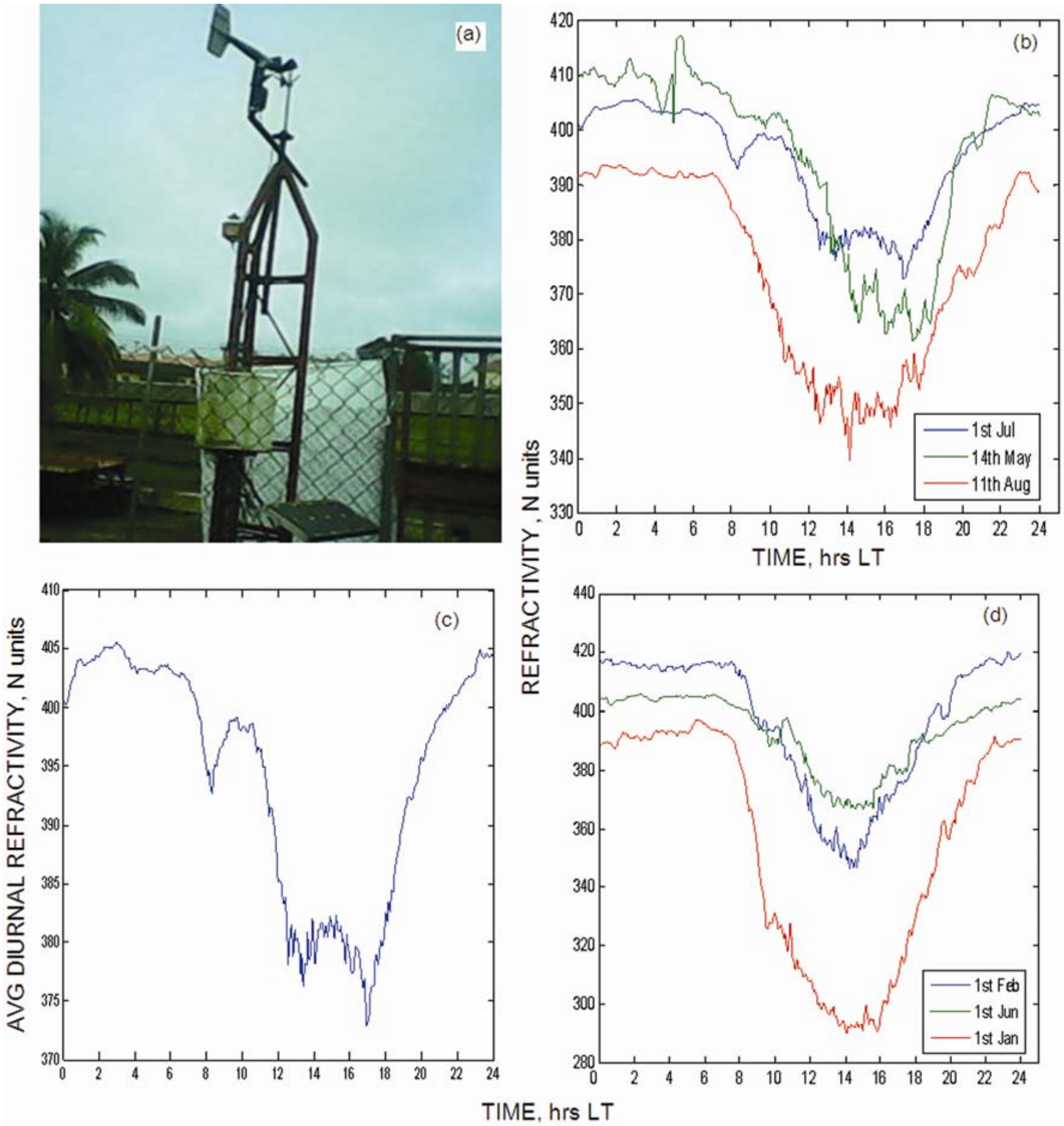

Fig. 1 — (a) NECOP station at Mowe; (b) diurnal plot of comparison of refractivity for 1 July without rain, 14 May with rain between 05:00 and 10:35 hrs LT; and 11 August (within the period of August break) against time; (c) average diurnal plot of refractivity during the month of July; and (d) diurnal plot of comparison of refractivity during the dry season (1 January and 1 February) which also coincides with harmattan period and wet season (1 July)

$$\boldsymbol{e_s} = 6.11\exp[19.7\boldsymbol{t}/(\boldsymbol{t}+273)] \quad \ldots(2)$$

For any relative humidity, $\boldsymbol{H}\%$,

$$\boldsymbol{e} = \boldsymbol{He_s} \quad \ldots(3)$$

The gaseous constituents (water vapour) influence the propagation of radio wave both by absorption of energy and variation in the refractive index.

3 The Nigerian Environmental Climatic Observing Program (NECOP)

NECOP is a project designed to establish a network in real time of meteorological and climatological observing stations spatially located across Nigeria through telemetry technology with five minutes update cycles[11,12]. It measures air temperature (°C), atmospheric pressure (mb), relative humidity (%), wind speed (ms^{-1}), direction (°N), soil moisture (%), soil temperature (°C) and rain rate (mm min^{-1}). In the present study, emphasis is placed on the diurnal, weekly and monthly variations in meteorological data obtained to determine the refractivity at 5 minutes interval for three years (2011-2013) during the dry/ harmattan and wet season. Equations (1 and 3) are used to generate the profile of surface refractivity (***N***) and water vapour pressure (***e***).

4 Results and Discussion

4.1 Diurnal variations of the meteorological parameters

Figure 1(b) shows a typical comparison of diurnal variations of the surface refractivity at Mowe, which varies diurnally from 00:00 to 23:59 hrs LT. In general, for most of the selected days, the diurnal refractivity profile increases slowly from 00:00 hrs to about 03:00 hrs LT (in the night) before it starts to decrease. The value decreases sharply around 06:00 hrs to about 07:30 hrs LT and continuously decreases until about 13:30 hrs LT in the afternoon. It has minimum value around 16:00 hrs LT before rising again. The profile of diurnal refractivity for 14 May was different from the other two selected days because it rained between 05:00 and 10:30 hrs LT with peak of 417 N-units at 05:20 hrs LT while the minimum was 360 N-units at about 17.20 hrs LT. 11 August was selected as another typical day because of the popular short break in raining season usually termed the ‘August break’ in the southern part of Nigeria. The day has almost constant peak refractivity of 392 N-units between 01:30 and 07:00 hrs LT and minimum of 372 N-units around 14.15 hrs LT. Surface refractivity was high throughout 1 July with minimum of 373 N-units at about 16:30 hrs LT and maximum of 405 N-units around 03:30 hrs LT. Figure 1(c) shows the plot of average diurnal refractivity during the month of July and Fig. 1(d) shows the diurnal plot of refractivity during the selected days (1 January and 1 February), which fall in dry season and which also coincide with harmattan period compared with a day in the wet season (1 July). The pattern of graphs obtained for the wet term for surface refractivity and relative humidity are shown in Figs 2(b and d). The plot of $\boldsymbol{N}_{\mathrm{dry}}$ against time is in the reverse direction to that of temperature with one-cycle variation per day as shown in Figs 2(a and c) for comparison. It is pertinent to note that the diurnal variations of the surface radio refractivity follow the same pattern with the relative humidity. Notwithstanding, the values of refractivity are high for all the days selected with either slight increase or decrease. This is the attribute of a coastal region due to its proximity to the Atlantic Ocean and hence, characterized with high relative humidity and extensive cloud cover. Low values of refractivity were observed on 1 January as compared to 1 February even though the two days fall in dry/harmattan season. There is a pronounced harmattan effect on 1 January as compared to 1 February.

The diurnal variation of the wet term of surface refractivity have been previously observed, and its profile correlated with the variation of VHF and UHF field strength measurements across the Southwest part of Nigeria[13,14]. This observation may explain the low signal level often received in the afternoon period, especially from distant transmitting stations.

4.2 Weekly and monthly variations of the meteorological parameters

The properties of lower atmosphere are highly variable and change hourly, daily, and even monthly. Therefore, there is need to see the picture of the variations weekly and monthly. Figures 3(a and b) are the profiles of the relative humidity and refractivity for a typical week in the months within the dry season (1-7 January) and wet season (1-7 June), respectively. The highest value of the refractivity is 418 N-units in June and the least of 287 N-units in January.

Typical monthly variations are also compared for months of June and August as shown in Fig. 4(a). Refractivity is lower in August as compared to June because of a sudden drop in relativity humidity due to slight rain cessation, with or without light shower usually termed as ‘August break’. January (dry season) and June (wet season) were also compared as shown in Fig. 4(b), the refractivity is high towards the end of January because the rain is about to set in (though there is no rain in January) but the relative humidity and temperature are high with relatively constant pressure. The variation in refractivity pattern of June is also fairly constant throughout the month as compared to January.

4.3 Annual distribution of surface radio refractivity

The annual distribution of radio refractivity is typified with a peak of double maximum during March-April and October-November termed primary and secondary peak, respectively in the three years

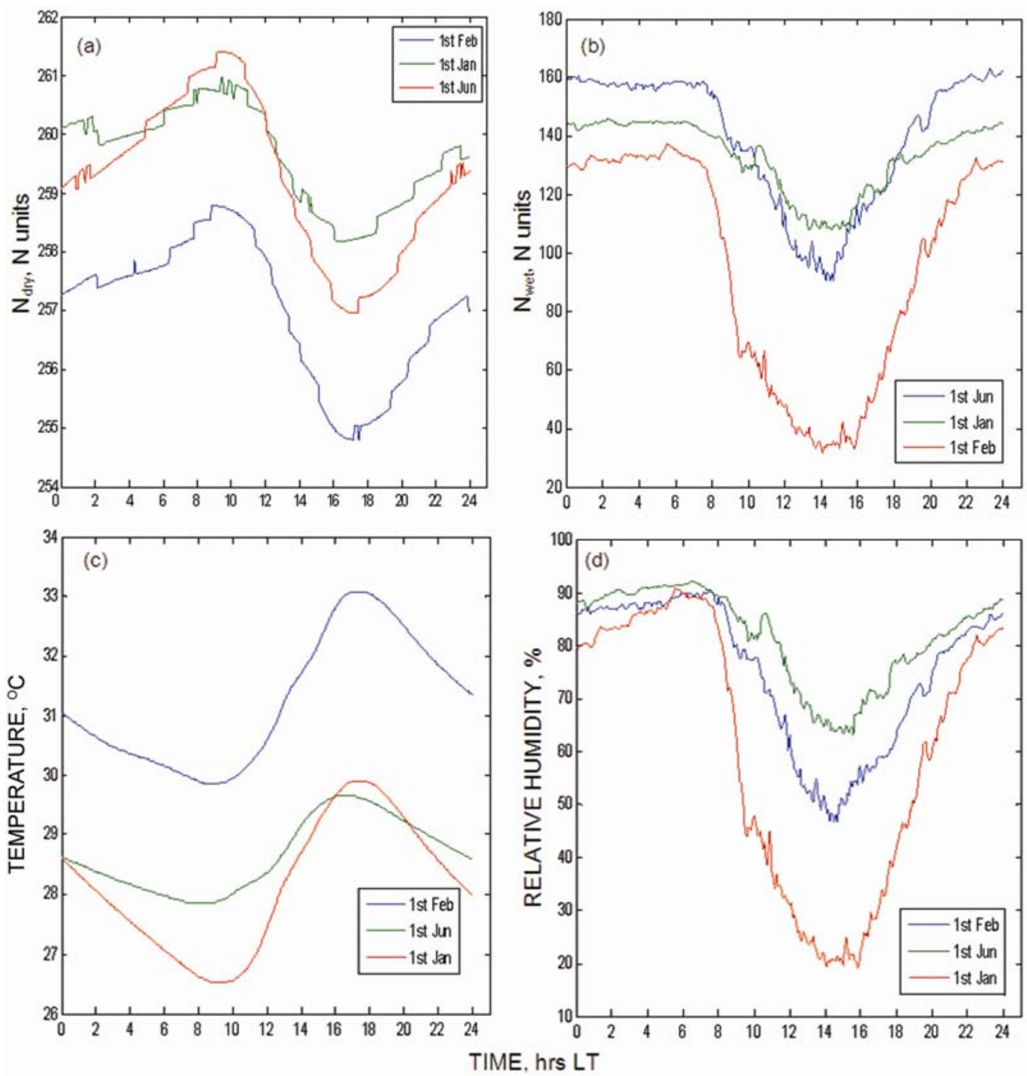

Fig. 2 — Comparison of diurnal plot of: (a) N_{dry} and (b) N_{wet} (c) temperature and (d) relative humidity against time for dry season (1 January and 1 February) and (1 June) for wet season

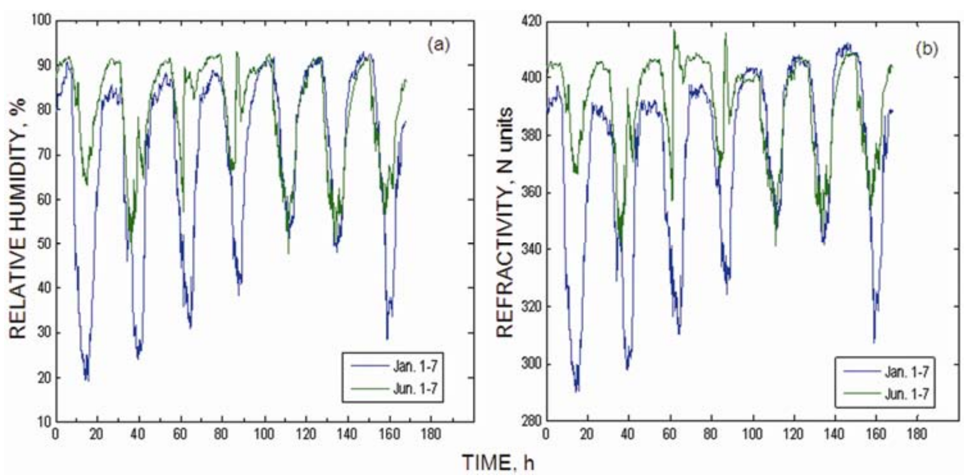

Fig. 3 — Weekly comparison of: (a) relative humidity and (b) refractivity against time for a typical dry season (1-7 January) and wet season (1-7 June)

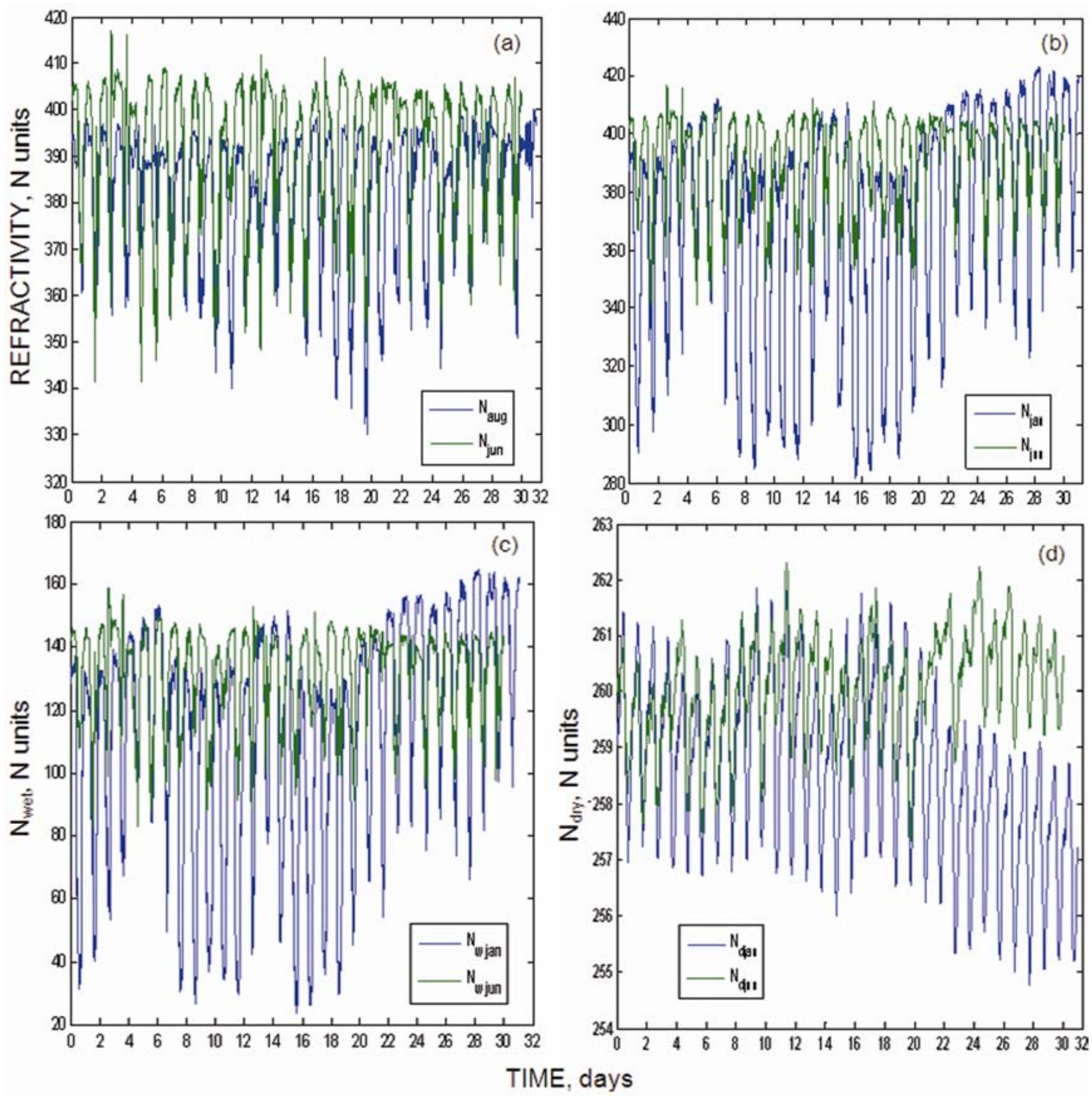

Fig. 4 — Comparison of monthly plot of: (a) refractivity variations for June and August against time; (b) refractivity variations for January and June against time; (c) N_{wet} for June and January against time; and (d) N_{dry} for June and January against time

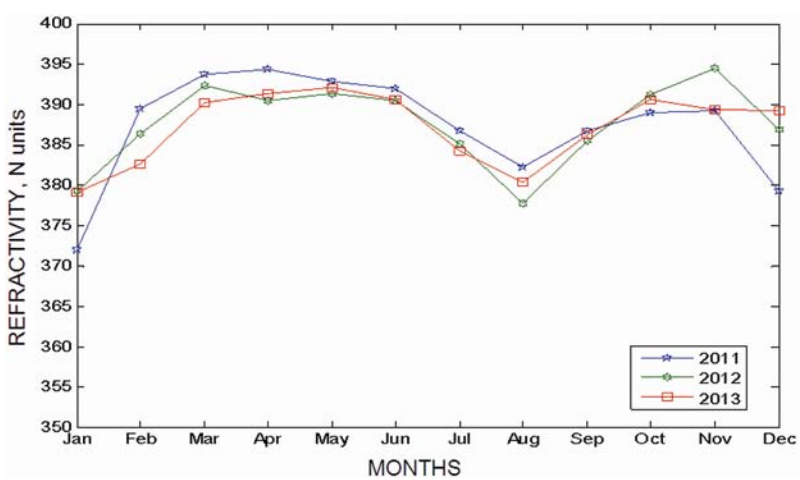

Fig. 5 — Seasonal variation of surface refractivity for the years 2011, 2012 and 2013

of available data for this work as shown in Fig. 5. The primary peak occurs with the appearance of northward advance of the ITD with the deepening of the south-westerly flow. The secondary peak resulted from the southward recession of the ITD, while the observed dip around August is due to a short period with low water vapour pressure popularly called the August break in the locality (south-western region of Nigeria). This feature has been attributed to the position of ITD line, which oscillates northwards to reach a northernmost position in August. The short period, which normally last for about three weeks is believed to be a consequence of some factors, which may include coastal upwelling and northern advance of the sub-tropical high pressure systems of the Southern Atlantic Ocean[5,16,17]. Figures [4(a) and 5] further substantiate the acclaimed fact that the refractivity in August is lower compared to that of June. Thereafter, the ITD began its seasonal southward movement to reach its peak in December. The decadal movements and average monthly positions of the ITD are, in most cases, above normal but at times lagg behind. The higher than normal ITD positions result to the high rainfall in the coastal area.

5 Conclusion

The diurnal patterns of the surface radio refractive index at Mowe station are studied. The diurnal, weekly, monthly and the seasonal patterns of surface refractivity distribution may be due (in part) to the local topography and also the migration of the oscillatory movement of ITD. This movement dictates and controls the weather of a particular location, and hence, influences the radio refractivity. The station experienced a phenomenon, which exhibited a double refractivity maximum with peaks at about March / April and October / November. The seasonal variation of the refractivity ranges between 372 and 395 N-units. On comparing the refractivity during wet and dry season, the value of refractivity during the wet season is higher than the refractivity during the dry season.

Acknowledgement

The authors express their gratitude to the Centre for Basic Space Science (CBSS) of National Space Research and Development (NASRDA), Nigeria for making available the data used in this work. They are also grateful to Prof L B Kolawole for his help during the study.

References

1. ITU-R, ***Recommendation 370-6: VHF and UHF propagation curves for the frequency range 30 MHz and 1000 MHz***, PN series Propagation in Non-Ionizing media (ITU, Geneva), 1994, pp 253-284.
2. ITU-R, The radio refractive index: Its formulae and refractivity data (ITU, Geneva), 2003, pp 435-459.
3. Kolawole L B, Climatological variations of surface radio refractivity in Nigeria, ***Bull Nigerian Inst Phys***, 4 (1980) pp 97–117.
4. Kolawole L B & Owonubi J J, The surface radio refractivity over Nigeria, ***Nigerian J Sci,*** 16 (1-2) (1982) pp 441-454.
5. Adeyemi B, Surface water vapour density and tropospheric radio refractivity linkage over three stations in Nigeria, ***J Atmos Sol-Terr Phys (UK)***, 68 (10) (2006) pp 1105-1115.
6. Willoughby A A, Aro T O & Owolabi I E, Seasonal variations of radio refractivity gradients in Nigeria, ***J Atmos Sol-Terr Phys (UK)***, 64 (2001) pp 417-425.
7. Ayantunji B G, Okeke P N & Urama J O, Diurnal and seasonal variation of surface refractivity over Nigeria, ***Prog Electromagn Res (Hong Kong),*** 30 (2011) pp 157-168.
8. Nigerian Meteorological Report, ***Nigeria climate review bulletin***, (2010) pp 1-10, http: //www.nimetng.org.
9. Falodun S E & Okeke P N, Radiowave propagation measurements in Nigeria (Preliminary reports), ***Theor Appl Climatol (Austria)***, 113 (2013) pp 127-135, doi: 10.1007/ s00704-012-0766-z.
10. Hall M P M, ***Effect of the troposphere on radio communication*** (IEE Electromagnetic waves series: 8) (Peter Peregrinus, UK)**,** 1979, pp 15-26.
11. Smith E K & Weintraub S, The constants in equation for atmospheric refractive index at radio frequencies, ***Proc Inst Radio Eng (USA)***, 41 (1953) pp 1035-1037.
12. Lane J A & Bean B R, A radio meteorological study, ***J Res Natl Bur Stand (USA)***, 67 (1963) pp 589-604.
13. Ajayi G O, Transhorizon proagation and its implications to radio propagation at VHF and higher frequencies in Nigeria, ***Nigerian J Eng,*** 17 (1982a) pp 72-75.
14. Agbo G A, Tropospheric refractivity dependence on atmospheric weather conditions in Jos, Nigeria, ***J Basic Phys Res (Nigeria)***, 2 (2) (2011) pp 1-6.
15. Owolabi I E & Williams V A, Surface radio refractivity patterns in Nigeria and the southern Cameroons, ***J West African Sci Assoc (UK)***, 15 (1) (1970) pp 3–11.
16. Adedokun J A, West Africa precipitation and dominant atmospheric mechanism, ***Arch Meteorol Geophys Bioclimatol A, Meteorol Geophys (Austria)***, 27 (1978) pp 289-310.
17. Adedokun J A, Surface humidity and precipitable water vapour linkage over west and central Africa: Further clarification and evaluation of existing models, ***Int J Climatol (UK)***, 9 (1989) pp 425-433.