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Effect of Primary Radio Climatic Variables on Tropospheric Surface Radio Refractivity Over 3 Stations in Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. Author AIK designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors KFO and KAA managed the analyses of the study. All authors read and approved the final manuscript.

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ABSTRACT

This study investigates the effect of primary radio climatic variables on the tropospheric surface radio refractivity across three stations (Makurdi (7.7322° N, 8.5391° E), Jos (9.8965° N, 8.8583° E) and Lagos (6.5244° N, 3.3792° E) in Nigeria. Two years (January 2008-December 2009) primary radio climatic variables data (temperature, pressure and relative humidity) obtained from the archive of the Tropospheric Data Acquisition Network (TRODAN) of the Centre for Atmospheric Research (CAR), which is an activity centre of the Nigeria National Space Research and Development Agency (NASDRA) was used for this study. The measurement was made at 30 minutes interval for a complete 24 hours cycle. The results obtained establish the variation of temperature and relative humidity to refractivity across the region.

Keywords: Radio climatic variables; surface refractivity; trodan; diurnal refractivity.

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1. INTRODUCTION

The earth atmosphere exists in strata or layers. The lowest layer is what is referred to as the earth troposphere. The troposphere is the lowest part to the earth surface where most weather phenomenon such as Rain, fog, dew, occur. It extends from the earth surface to an altitude of about 10 km at the earth poles and 17 km at the equator and tends to affect radio frequencies above 30 MHz. Radio waves travel freely in space with the speed of light. They are form of electromagnetic waves which do not require a medium for their propagation. Radio waves that travel in the troposphere are influenced by the different component that makes us the atmosphere. Due to the dynamics of the primary radio climatic variables (temperature, pressure, and humidity) in the lowest atmosphere (troposphere) the refractive index of air varies from one point to another [1,2,3].Radio wave propagation phenomena such as ducting, scintillation, fading which causes attenuation of radio signals occur as a result of refractivity [4].

The radio refractivity which is a function of pressure, temperature and humidity vary for different space and time [4]. Generally, atmospheric radio wave refractivity varies inversely as a radio signal or wave. However, research has also shown that the wind direction has a slight negative impact on the association between Radio signals and refractivity [5].

Some researchers have worked on refractivity variation and according to Adediji and Ajewole studied the Distribution of radio refractivity gradient and effective earth radius factor (k -factor) over Akure and they found the value of refractivity to be high during the rainy season and low during the dry season[6]. Ayantunji and Okeke 2013 study the diurnal and seasonal variation of surface refractivity over Nigeria and it was found that the value of surface refractivity is higher at night and early mornings and generally low during noon [7].

Agbo (2011), investigate the dependence of surface radio refractivity on atmosphere parameters such as pressure, relative humidity and temperature in Jos, Nigeria, 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 [8]. 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 Inter-tropical discontinuity (ITD) [9].

Planning of radio broadcasting services above 30 MHz has been on recommendation 370 of the 'International Telecommunication Union (ITU-R)' [10]. However, available data are from measurements performed in Europe, North America, and Japan with little inputs from the tropical region, particularly Africa. The ITU in response to these observed lapses initiated a radio-wave propagation measurement campaign in Africa in 1984 with two experiments performed in Burkina Faso between 1986 and 1989 with several investigations further conducted in some locations in Africa [11]. Though, none of these studies was carried out in Nigeria; and for optimized planning of radio services, data which take into account the specific climatic condition is required [12]. It, therefore, becomes essential to bridge the knowledge gap for a proper understanding of the propagation mechanisms associated with the country.

This research work focuses on an in-depth analysis of the effect of temperature, pressure, and humidity. It presents the result of two years of measurement of primary radio climatic variables (temperature, humidity, and pressure) of the troposphere for three locations in Nigeria. The measured data were used to compute the surface refractivity, the daily refractivity and the variation of the radio climatic variables with refractivity values. The result presented in this paper is therefore expected to make a significant contribution to the planning of radio terrestrial links.

2. RESEARCH SITE AND DATA ACQUISITION

This study was carried out in three (3) stations in Nigeria as shown in Fig. 1 namely: Lagos in the south-western part of Nigeria, Makurdi, and Jos in the North-central part of Nigeria.

The instrument used for the measurement of the atmospheric parameters used for this study is a wireless weather station is shown in Fig. 2, which consists of a solar panel that converts the sun rays into electrical energy, a rain collector that measures the amount of rainfall and a tipping bucket rain gauge that measures the rain rate, sensors that measure temperature, pressure, relative humidity, UV index dose, solar radiation, and an anemometer that measures wind speed and direction. It is calibrated to measure the weather parameters in 5 minutes integration time. The data is stored in the data logger and then copied to a computer for analysis. The equipment was installed in all the locations considered for this study by the Centre for Atmospheric Research, (CAR) Anyigba, Kogi-State. The centre is one of the activity centres of the National Space Research and Development Agency, (NARSDA) in Abuja Nigeria. Tropospheric Data Acquisition Network (TRODAN) is a unit of CAR.

Table 1. Geographic coordinate and altitude of the research site

Research site	Latitude	Longitude	Elevation	Climate
Lagos	6.30^0N	3.20^0E	41 m	Monsoonal
Jos	9.88^0N	8.86^0E	1217 m	Guinea Savannah
Markurdi	7.73^0N	8.53^0E	104 m	Guinea Savannah

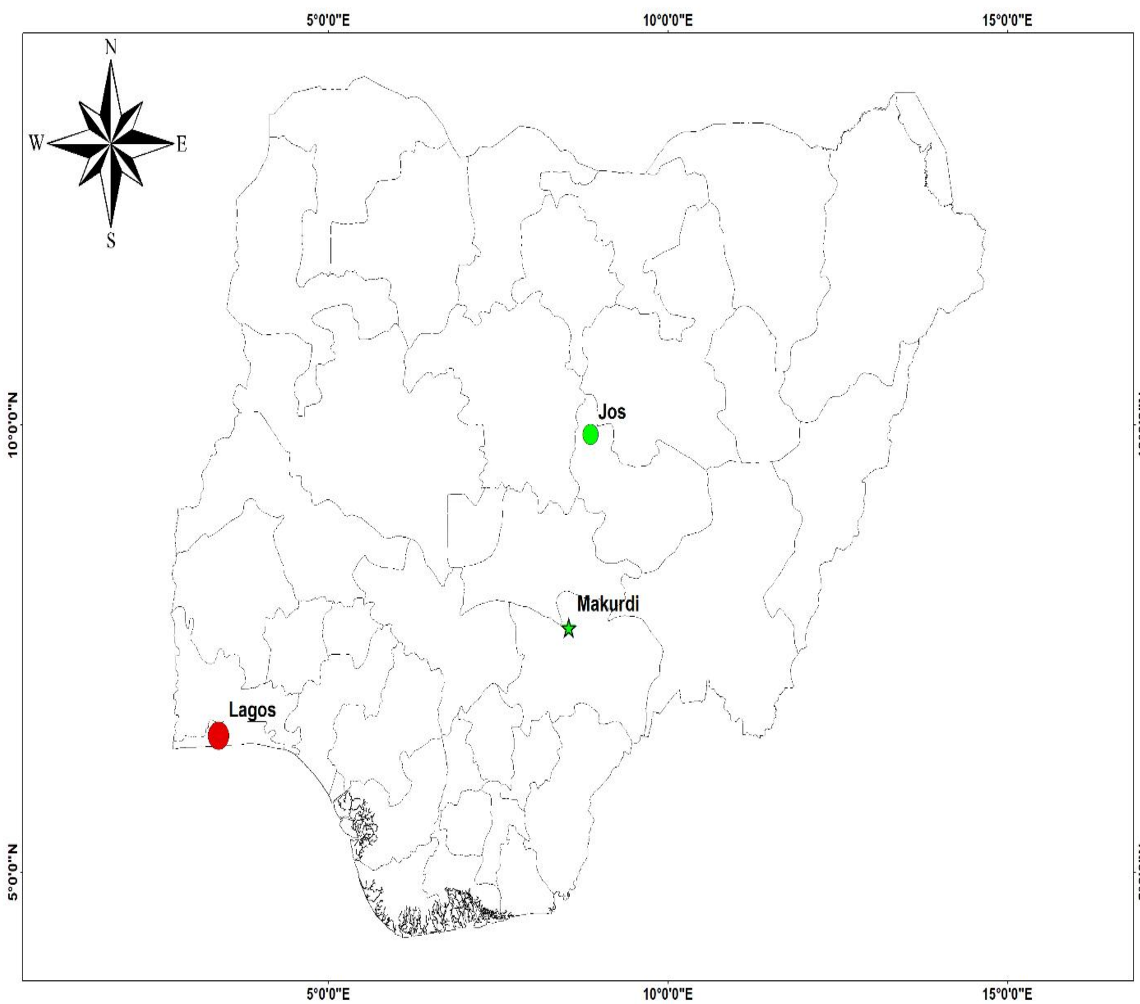


Fig. 1. Map of Nigeria indicating the study location

Fig. 2. Tropospheric data acquisition network (TRODAN) set up at a location

2.1 Surface Radio Refractivity (N_s)

When light waves travel through a medium of material composition, part of its energy is lost to the medium in a process termed refraction [13]. Hence, microwave signal propagation in the troposphere suffers refraction; a consequence of the atmospheric constituents which include temperature, pressure, humidity, water vapour, and other greenhouse gases. Radio refractivity N is thus a measure of the deviation of refractive index, n of air from unity scaled – up in parts per million and given by ITU-R [14]:

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

where n is refractive index and N is a dimensionless quantity expressed in N−units. In terms of measured meteorological quantities, the refractivity N can be expressed as:

$$\mathrm{N} = 77.6\frac{\mathrm{P}}{\mathrm{T}} + 3.73 \text{ X } 10^5 \frac{\mathrm{e}}{\mathrm{T}^2} \quad (2)$$

Eqn. 2 is categorized into two (2)

$$\mathrm{N} = N_{dry} + N_{wet} \quad (3)$$

Where;

the $N_{dry} = 77.6\frac{P}{T}$ and the $N_{wet} = 3.73 \times 10^5 \frac{e}{T^2}$

P is the atmosphere pressure (hPa), e is the water vapour pressure (hPa) and T is the absolute temperature (K).Eqn.3 may be used for radio frequency up to 100 GHz [9].

The vapour pressure is also related to the relative humidity H (%)

$$e = \frac{He_s}{100} \quad (4)$$

e_s is the saturated vapour pressure at the given air temperature, and is expressed as

$$e_s = 6.1121\mathrm{EXP}\left[\frac{17.502t}{(t+240.97)}\right] \quad (5)$$

Pressure (P) and vapour pressure (e) decrease rapidly with height while temperature (T) decreases slowly with height [15].

The surface radio refractivity, Ns is the refractivity determined at the ground level of the study location. Its value is sensitive to changes in (i.e. a function of) temperature, pressure, and humidity [16] and therefore decrease on the average with elevation. Elevation angle errors and range errors can also be predicted from Ns value [17].

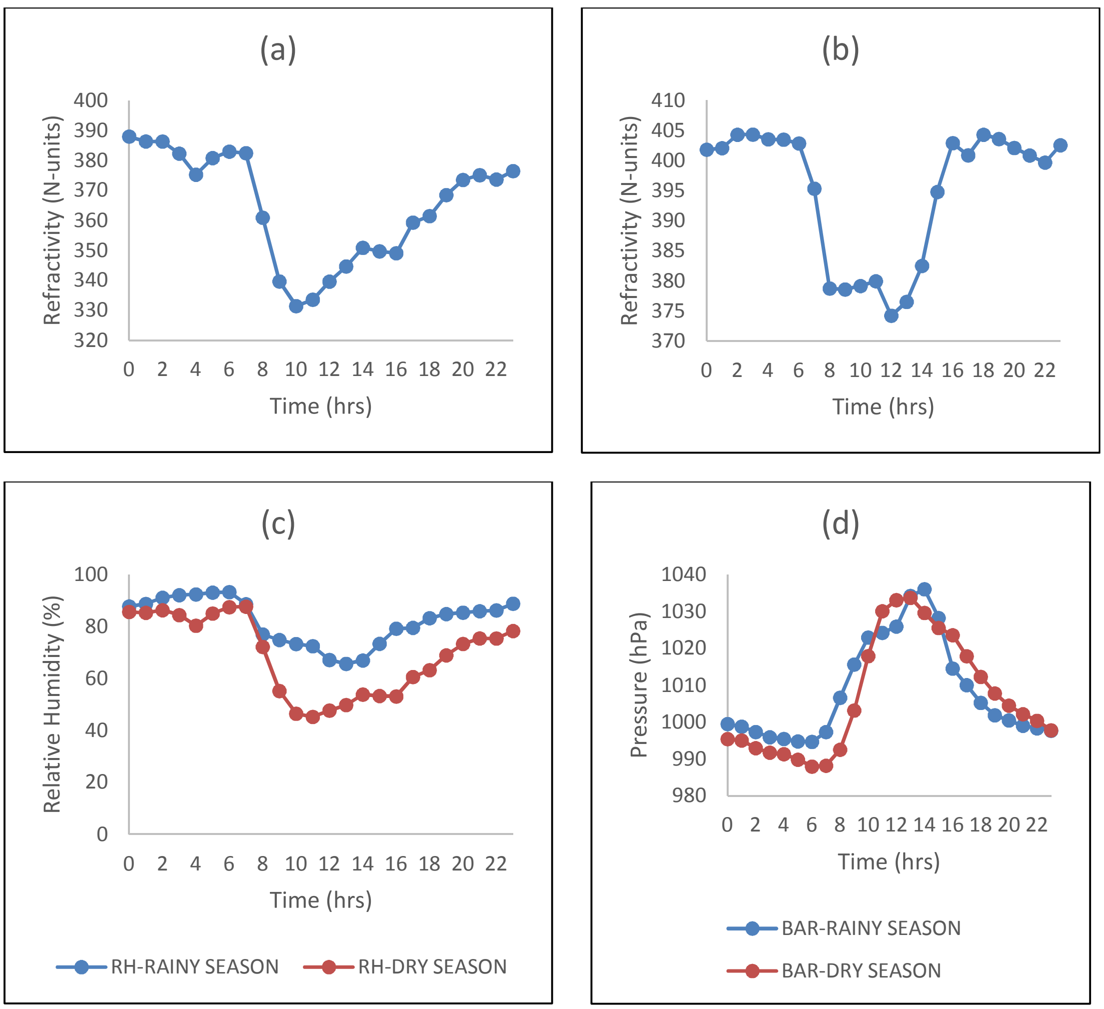
Surface radio refractivity is also known to have a high correlation with radio field strength values, thus, a good knowledge of Ns is particularly useful in planning terrestrial radio links [18].

3. RESULTS AND DISCUSSION

Fig. 3(a) and 3(b) depicts the diurnal variation of surface radio refractivity over Lagos for the dry and rainy season. During the dry season as shown in Fig. 3(a), the N values are found to be high at the early hours of the morning with maximum value of about 390 N-units at 0:00 hr. before peaking downward at 8:00 hr. The lowest value of refractivity is observed around at 10:00 hr., 11:00 hr., before peaking upward for the rest of the day.

During the rainy season as shown in Fig. 3b, maximum value of refractivity is observed in the early hours of the day with a maximum of about 405 N-units at 2:00 hr. Low values of refractivity are observed at 8:00 hr. LT, 9:00 hr., 10:00 hr. LT, 12:00 hr. LT, and 13:00 hr. LT. The value increases gradually from 13:00 hr. to a maximum of 405 N-units at 18:00 hr. from this, it was evident that high values of refractivity always occur at the evening and night hours.

The radio refractivity (N) which is a function of Atmospheric pressure, Temperature and Humidity is directly proportional to the pressure and inversely proportional to the temperature. This implies that the higher the temperature, the lower the value of N.



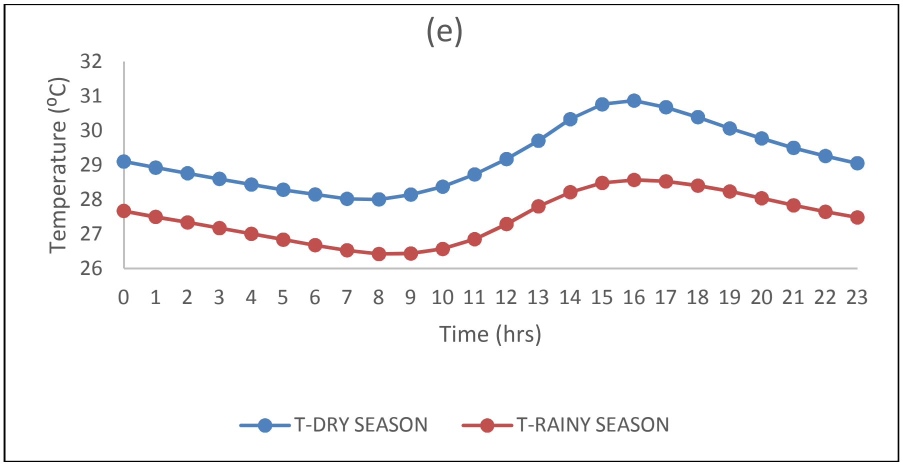


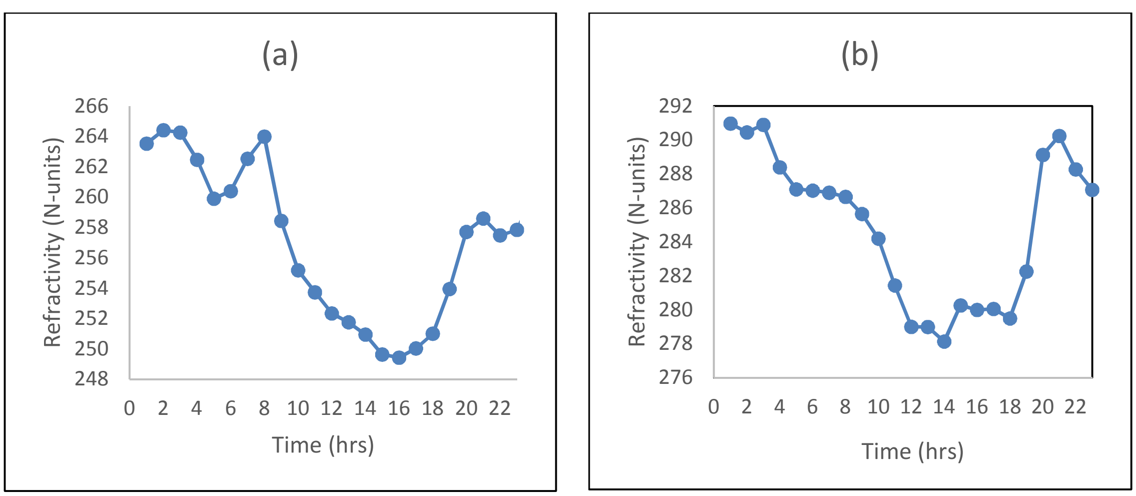
Fig. 3. (a) Diurnal Variation of Surface Refractivity over Lagos for Dry Season. (b) Diurnal Variation of Surface Refractivity over Lagos for Rainy Season. (c) Diurnal Variation of Relative Humidity over Lagos for Dry and Rainy Season.(d) Diurnal Variation of Pressure over Lagos for Dry and Rainy Season. (e) Diurnal Variation of Temperature over Lagos for Dry and Rainy Season

The diurnal variation of surface radio refractivity for the dry and rainy season in Jos is shown in Fig. 4(a) and 4(b) respectively. The value of refractivity for both profiles shows a low value of refractivity in the afternoon and high values in the morning and evening hours. The maximum value of refractivity during the dry season as shown in Fig. 4(a) is observed to be 264 N-units around 2:00 hr. and a minimum value of about 250 N-units around 16:00 hr.

During the rainy season as depicted in Fig. 4(b). Maximum value of refractivity is observed during the early hours of the day at 1:00 hr. LT. with a maximum value of about 291 N-units and the lowest value is observed at 14:00 hr. LT with a value of 278 N-units.

The variation of refractivity in both the rainy and dry season is consistent with the humidity profile shown in Fig. 4(d). The variation follows the trend of the humidity profile; hence the diurnal variation in Jos is attributed to the wet term of refractivity.

The diurnal variation of surface radio refractivity profile during the rainy season in Makurdi is shown in Fig. 5(a). The profile during the rainy season increases gradually to about 379 N-units around Noon and gradually dropped to a



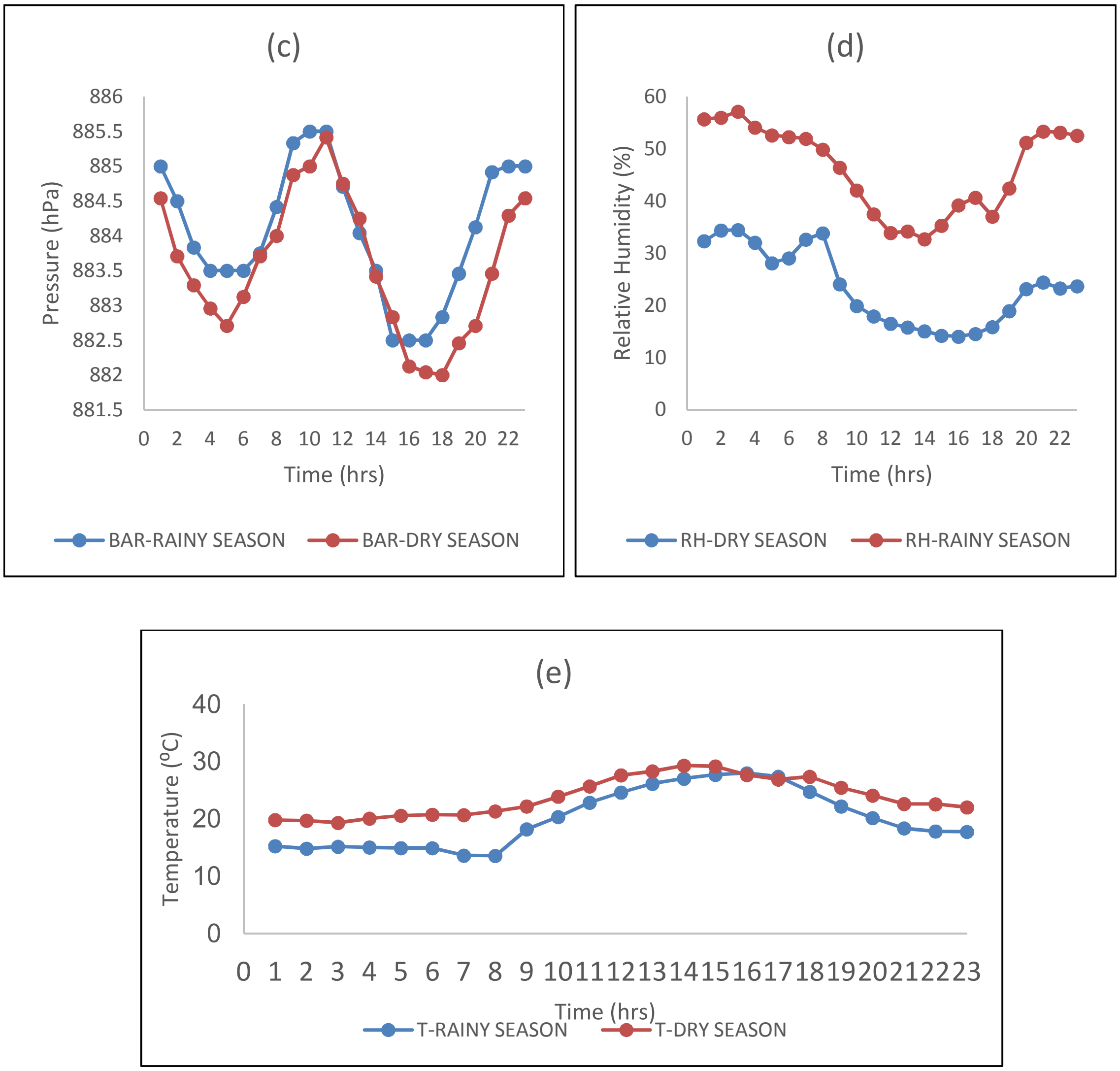


Fig. 4. (a) Diurnal Variation of Surface Refractivity over Jos for Dry Season. (b) Diurnal Variation of Surface Refractivity over Jos for Rainy Season. (c) Diurnal Variation of Pressure over Jos for Dry and Rainy Season. (d) Diurnal Variation of Relative Humidity over Jos for Dry and Rainy Season. (e) Diurnal Variation of Temperature over Jos for Dry and Rainy Season

minimum of about 374 N-units around 16:00 hr. local time (LT). It slightly rises to another small peak of about 375 N-units around 20:00 hr. LT and dropped again for the rest of the day.

The peak value of refractivity at Noon can be explained by the pressure profile shown in Fig. 5(c) maximum values of pressure are obtained at noon. This corresponds to high value of refractivity at that hour. The refractivity profiles during the dry season in Makurdi is shown in Fig. 5(b). The profile shows a gradual increase from the early hours of the morning and a peak of about 324 N-units around 2:00 hr. LT and 323 N-units around 9:00 hr.LT, and decease gradually to a minimum of about 285 N-units around 16:00 hr. LT, and gradually increases for the rest of the day. The variation pattern is in line with the humidity and temperature profile.

At 16:00 hr. LT, the values of humidity rises and the value of temperature decreases for the rest of the day.

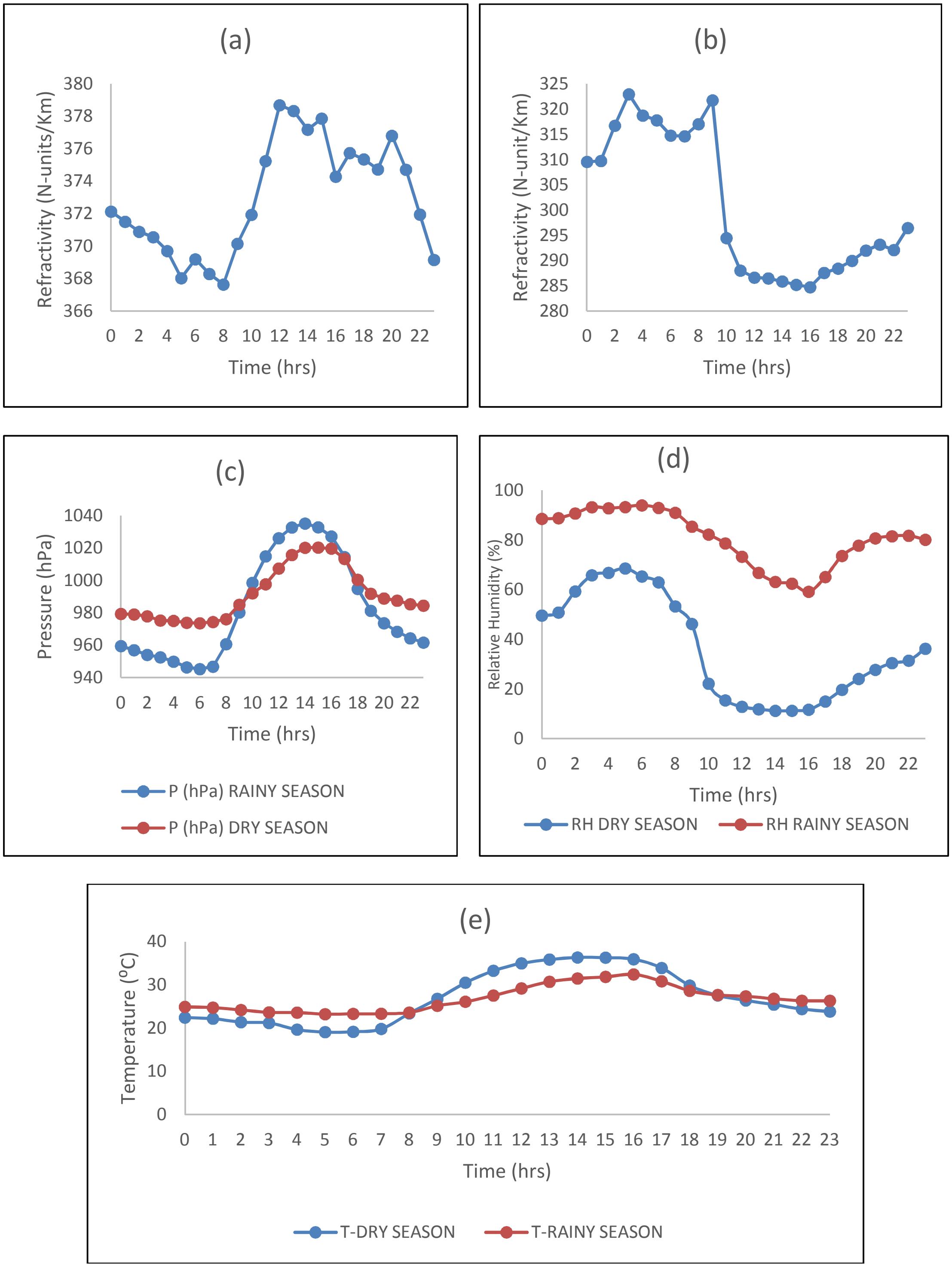


Fig. 5. (a) Diurnal Variation of Surface Refractivity over Makurdi for Rainy Season. (b) Diurnal Variation of Surface Refractivity over Makurdi for Dry Season. (c) Diurnal Variation of Pressure over Makurdi for Dry and Rainy Season.(d) Diurnal Variation of Relative Humidity over Makurdi for Dry and Rainy Season. (e) Diurnal Variation of Temperature over Makurdi for Dry and Rainy Season

4. CONCLUSION

Two-year (Jan. 2011-Dec. 2012) archived data of atmospheric variables: temperature, pressure and relative humidity obtained for, Jos, Lagos, and Markurdi locations were employed in this study.

The effects of primary radio-climatic variables on Tropospheric surface radio propagation in Jos, Lagos, and Makurdi, Nigeria has been investigated. Analysis of refractivity, relative humidity and temperature revealed that the variation of refractivity varies seasonally from one region to another. At a low level, Variation of surface refractivity is consistent with the Humidity profile for both the dry and rainy season.

At the coastal and guinea savannah regions, higher and almost uniform values of relative humidity and refractivity parameters are observed throughout the year.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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