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To cite this article: M. Balarabe *et al* 2021 *J. Phys.: Conf. Ser.* **2034** 012029

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# Radio refractivity computations in Kano, Northwestern Nigeria

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**Abstract.** This paper is the study of radio refractivity computations in Kano State ( $12.43^{\circ}N, 8.19^{\circ}E$ ), Northwestern Nigeria. One-year meteorological data of relative humidity, pressure, temperature, and dew point were obtained from Nigerian Meteorological Agency (NiMET) and the statistical values of tropospheric radio refractivity were evaluated. The data were further analysed to obtain the refractivity gradient values. From the results, the computed refractivity has peak values of 290 N-Units, 231 N-Units, 158 N-Units and 125 N-Units at heights of 1.5 km, 3 km, 6 km and 8 km respectively, while minimum values of 245 N-Units, 170 N-Units, 146 N-Units and 114 N-Units were obtained at the same respective heights of 1.5 km, 3 km, 6 km and 8 km. For the refractivity gradients, the computed values ranged from -50 N-Units/km to -24 N-Units/km at 3 km, -29 N-Units/km to -22 N-Units/km at 6 km and from -25 N-Units/km to -19 N-Units/km at 8 km.

Keywords: Atmospheric data, Radio refractivity, Refractivity gradient.

## 1. Introduction

The earth's atmosphere is a dynamic medium. Its properties vary with atmospheric factors such as air temperature ( $^{\circ}C$ ), dew point ( $^{\circ}C$ ), atmospheric pressure (hPa) and relative humidity (%). The lowest region of the earth's atmosphere is known as troposphere, ranging from the earth's surface to a height of 17 km at mid latitude, 6 km at the poles and approximately 18 km at the equator. In the lower atmosphere, the troposphere provides a huge impact on radio waves with frequencies above 30 MHz, though this effect becomes noticeable only at frequencies greater than 100 MHz [1].

The tropospheric refractive index is a function of pressure, humidity and temperature and this indicates that fluctuations of these atmospheric parameters would significantly affect the variation of the index of air refraction [2]. The phenomenon of radio communication is related to tropospheric refractivity. As electromagnetic waves propagate through the atmosphere (especially the troposphere), they are highly influenced by the constituents of the atmosphere. Refractive bending leads to stretching of the radio horizons beyond the optical horizons.

Some studies have shown that good correlation exists between radio field strength and  $N_s$  (surface radio refractivity) and that refractivity gradients which are obtained from  $N_s$  determine the refractive propagation of the atmosphere whether it is normal, sub-refractive, super-refractive or ducting layer [1,3]. These different types of propagation play vital roles in VHF (Very High Frequency), UHF (Ultra High Frequency) and microwave communications in the atmosphere. This study investigates the seasonal trend of radio refractivity and refractivity gradients as well as determine the refractive condition of the atmosphere over Kano State, Northwestern Nigeria.



## 2. Background

The refractivity,  $N$  of the earth's atmosphere is the difference between refractive index of air scaled up to a million and can be computed from parameters of pressure, relative humidity and temperature. According to [4], refractivity gradient is the difference between refractivity values at surface level and at a given elevation, such as between the surface and 1000 m. To have a more convenient value of radio refractivity,  $N$  is written as [1]:

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

where  $n$  is the refractive index of air.

At 30 GHz,  $N$  is given by [5]:

$$N = \frac{77.6}{T} \left( P + 4810 \frac{e}{T} \right) \quad (2)$$

Equation 2 can be rewritten as:

$$N = 77.6 \frac{P}{T} + 3.732 \times 10^5 \frac{e}{T^2} \quad (3)$$

where  $P$  is pressure (measured in millibars or hPa),  $T$  is temperature (Kelvin) and  $e$  is water vapour pressure (mb).

The water vapour pressure and relative humidity (%),  $H$  are related by [4]:

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

where  $e_s$  is saturated vapour pressure (hPa), expressed as:

$$e_s = 6.11 \exp\left(\frac{19.7t}{t + 273}\right) \quad (5)$$

$t$  is temperature (in °C)

The refractivity gradient (change in radio refractivity),  $\left(\frac{dN}{dh}\right)$  is computed using:

$$\left(\frac{dN}{dh}\right) = \frac{N_1 - N_s}{h_1 - h_s} \quad (6)$$

where  $N_1$  is refractivity at 1 km above ground,  $N_s$  is surface refractivity,  $h_1$  is height at 1 km,  $h_s$  is surface height and  $\frac{dN}{dh}$  is refractivity gradient.

The refractive conditions of the atmosphere with respect to the values of  $\frac{dN}{dh}$  are explained in details in [6].

## 3. Methodology

Daily data of atmospheric pressure, relative humidity and temperature measured for one year (2016) was used in this work. The atmospheric data was obtained from upper air station of the Nigerian Meteorological Agency, Abuja (NiMET). A radiosonde was used to measure the atmospheric weather elements. The radiosonde is an electronic transmitter used for daily ascent, carried into the atmosphere by a weather balloon and it comprises five sensors used to measure five weather parameters or elements namely atmospheric pressure, relative humidity, temperature, wind speed/direction and dew point temperature.

The weather balloon is usually launched to the sky at 1200 hours (12:00pm). The measurement is tracked with the aid of an antenna and sent to a Vaisala DigiCORA sounding System which is connected to a personal computer (PC). The Vaisala DigiCORA sounding System is an upper air package used for measuring atmospheric profiles. The DigiCORA integrates and stores all the data until the termination of the ascent. The stored data is decoded and printed automatically with the aid of a printer and the data is kept for analysis. The data is exported and logged in with date and time for reference purpose into Microsoft Excel package. Figure 1 shows the DigiCORA and Radiosonde sounding system.



Figure 1: DigiCORA and Radiosonde sounding system from [7]

### 3.1 Data Analysis

The collected daily data at four different height levels were inputted into the PC which was analysed to determine the water vapour pressure, saturated water vapour pressure, surface refractivity and refractivity gradient using equations (1) – (6). The atmospheric data were obtained at different height levels of between 1.5 km and 21 km above the earth's surface but some atmospheric parameters were missing at various heights above 8 km. Therefore, refractivity values computed in this paper were only done at four (4) heights. These are 1.5 km, 3 km, 6 km and 8 km.

Also, since atmospheric data at surface level was not available, the computed gradients at each height were done with reference to refractivity values at 1.5 km.

## 4. Results and Discussion

The study area experiences two (2) distinct seasons yearly: wet and dry season. The wet season extends from May to October, while the dry season stretches from November to April. Figure 2 presents the mean monthly radio refractivity variation for the one-year period.

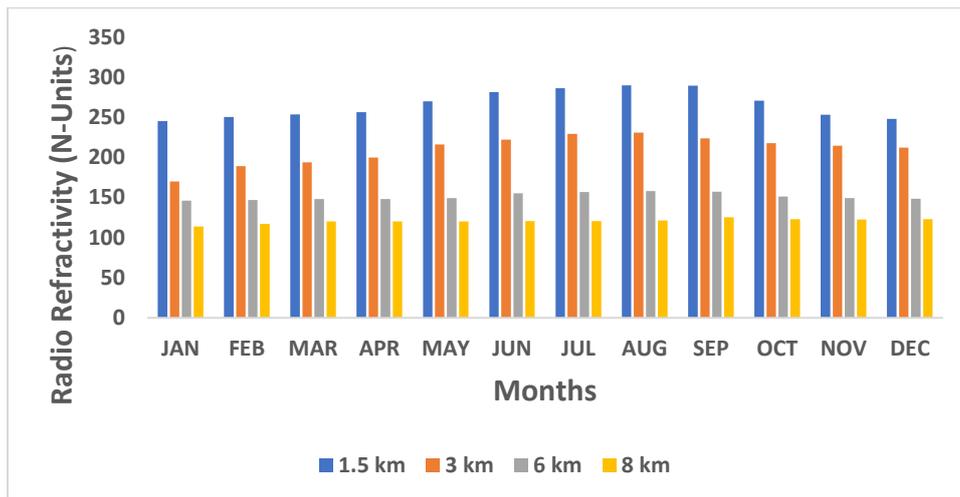


Figure 2: Mean seasonal variation of radio refractivity

From Figure 2, a decrease in refractivity values is observed as the heights increase from 1.5 km to 8 km in all the months. Also, refractivity values are lower in the dry months of January to April and from November to December implying low relative humidity, while higher values are recorded in the wet months of May to October, indicating elevated relative humidity levels. This trend is observed at all the heights. The months of November, December and January ushers in Harmattan which is characterised by cold nights and dry day time ensuring low refractivity.

Peak values of 290 N-Units, 231 N-Units and 158 N-Units at heights of 1.5 km, 3 km and 6 km respectively were recorded in August except at 8 km height whose peak value of 125 N-Units occurred in September. Minimum values of 245 N-Units, 170 N-Units, 146 N-Units and 114 N-Units computed at the respective heights of 1.5 km, 3 km, 6 km and 8 km were recorded in January. A gradual increase of refractivity is observed in April with the commencement of the wet season. Also, there is a steep but steady increase and little fluctuations in refractivity values between May and October.

Figure 3 depicts the average seasonal variation of radio refractivity gradients over Kano State at three different heights: 3 km, 6 km and 8 km.

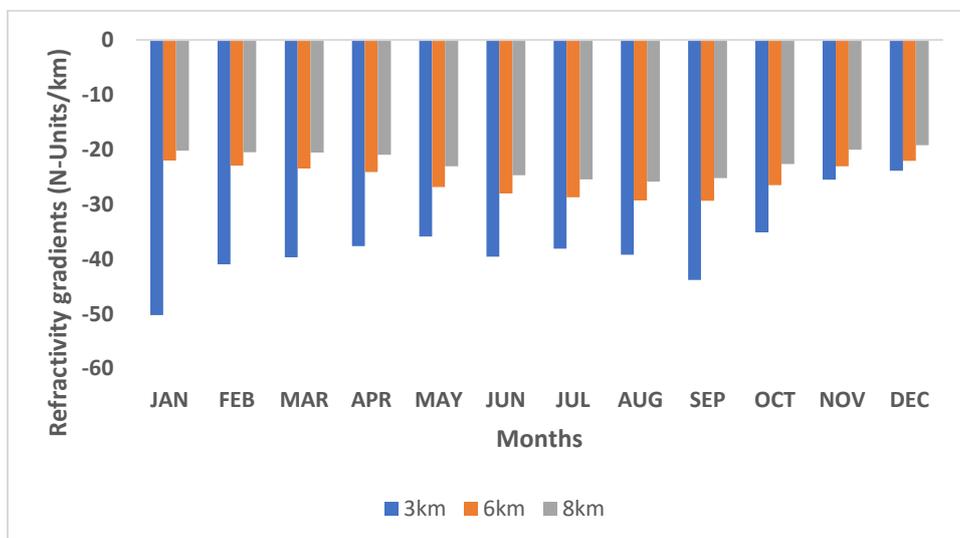


Figure 3: Mean seasonal variation of refractivity gradients.

From Figure 3, the results show that refractivity gradients varied from -50 N-Units/km in January to -24 N-Units/km in December at 3 km. At 6 km, it ranged from -29 N-Units/km in August/September to -22 N-Units/km in December/January, while it varied from -26 N-Units/km in August to -19 N-Units/km in December at 8 km. These computed refractivity gradient values showed that the atmosphere over Kano is generally sub-refractive.

## 5. Conclusion

Radio refractivity computations in Kano State has been carried out in this study. The observed results of both refractivity and refractivity gradients can be used to categorise the prevailing atmospheric refractive conditions existing in Kano State. Refractivity values were low during the dry season due to increase in temperature and low relative humidity, while the wet season refractivity was high due to rise in relative humidity. Also, refractivity values were observed to decrease with increase in height levels. Peak values of 290 N-Units, 231 N-Units, 158 N-Units and 125 N-Units at heights of 1.5 km, 3 km, 6 km and 8 km respectively were recorded in the wet season, while minimum values of 245 N-Units, 170 N-Units, 146 N-Units and 114 N-Units at the respective heights of 1.5 km, 3 km, 6 km and 8 km were recorded in the dry season. Also, refractivity gradients computed varied from -50 N-Units/km in January to -24 N-Units/km in December at 3 km, while it ranged from -29 N-Units/km in August/September to -22 N-Units/km in December/January at 6 km. At the height of 8 km, the gradients varied from -26 N-Units/km in August to -19 N-Units/km in December. The results derived from this work will be useful to radio engineers/scientists in the study area.

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