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Measurement of Radio Refractive index in the first 100 m layer over Minna in North Central Nigeria

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Abstract

Tropospheric radio refractivity at surface and 100 m levels is investigated from in-situ measurement of atmospheric pressure, temperature and relative humidity made in Minna (9° 37''N, 6° 30''E), North central Nigeria. Daily measurement of the atmospheric variables was made at 30 minutes interval. The instrument used is the Vantage PRO II Automatic Weather Station and the data used was for a period of 12 months (January to December 2008). The results obtained show that the values of refractive index at both levels were high in the morning and late evening/night hours while the values were low during the afternoon hours. Also, statistical analysis of radio refractive index gradients was carried out and the Cumulative frequency distribution shows that the atmosphere over Minna was sub refractive for about 50% of the time with positive gradients appearing occasionally, super refractive for about 40% of the time while normal refraction occurred for only 10% of the time.

Key words: Radio refractivity; refractivity gradient.

1. Introduction

Radio energy at frequencies above 30 MHz is not normally reflected by the ionosphere, therefore, variability in the characteristics of the received fields is attributed to variations in the radio refractive index of the lower atmosphere (Bean and Dutton, 1968). A study of the extent or manner of variation of the refractive index with changes in height has a marked influence on radio waves at the VHF, UHF and microwave bands. These atmospheric refractive index variations are due to changes in temperature, pressure and humidity (Afullo *et. al.*, 1998).

The radio refractivity of air is an important parameter to be considered in the propagation of radio waves through the atmosphere. Refractivity gradient statistics for the lowest 100 m from the surface of the Earth are used to estimate the probability of occurrence of ducting and multipath conditions (Batueva *et al.*, 1998; ITU-R, 2003). For an atmosphere which is horizontally homogeneous, pressure and temperature decrease with height. Changes in the dielectric constant are thus gradual. The effect of this is that a propagating radio wave is bent gradually from the less dense medium (greater altitude), to the more dense medium (lower altitude). In effect, the ray path is bent over the horizon, and tends to follow the curvature of the earth (Isaakidis and Xenos, 2004).

A number of studies on surface refractivity in Africa have been carried out. Owolabi and Williams (1970) computed surface refractivity values for Nigeria and Southern Cameroons using two years meteorological data from 30 stations. They observed that surface refractivity values based on long term meteorological data can be used to reliably predict diurnal and seasonal characteristics of radio signals. Kolawole and Owonubi (1982) also computed the values of surface refractivity for Africa using meteorological data for 202 stations from 1978 to 1979. They reduced surface values to sea level values, N_o in order to remove the dependence on elevation. Several other studies have also shown refractivity variations to be more pronounced in the tropical climate than temperate climate and the existence of a good correlation between monthly means of surface refractivity, N_S, and monthly means of refractivity decrease in the first kilometer above ground, ΔN (Mitra *et al.*, 1987; Aro and Willoughby, 1992; Willoughby *et al.*, 2001).

2. Refractivity theory

The atmospheric radio refractive index, n, can be computed by the following formula:

$$n = 1 + N \times 10^{-6} \tag{1}$$

where N is radio refractivity expressed by:

$$N = N_{dry} + N_{wet} = \frac{77.6}{T}\left(P + \frac{4810e}{T}\right) \tag{2}$$

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

$$N_{dry} = 77.6\,\frac{P}{T} \tag{3}$$

and the 'wet term' by:

$$N_{wet} = 3.73 \times 10^{5}\,\frac{e}{T^{2}} \tag{4}$$

where:

P = atmospheric pressure (hPa)

e = water vapour pressure (hPa)

T = absolute temperature (K)

(ITU-R, 1999)

The vapour pressure, e is given by:

$$e = \frac{H \times e_s}{100} \tag{5}$$

where H is the relative humidity and e_s is the saturated vapour pressure.

e_s is calculated from:

$$e_s = 6.11 \exp\left[(19.7t)/(t + 273)\right] \tag{6}$$

where t is the temperature in °C (Hall, 1979)

2.1 Refractivity gradient

The vertical gradient of radio refractivity in the lowest layer of the atmosphere is an important parameter for the estimation of path clearance and propagation effects such as ducting, surface reflection and multipath on terrestrial line-of-sight links (ITU-R, 1999). The change in radio refractivity, ΔN, is calculated from (ITU-R, 2003):

$$\Delta N = N_S - N_1 \tag{7}$$

where N_s is the surface refractivity and N_1 is the radio refractivity at a height of 1 km above the surface of the Earth. A normal or standard atmospheric refraction is one with median value of N decreasing at the rate of -40 N-units/km, i.e $dN/dh = -40$ N-units/km. Sometimes abnormal conditions occur which result in anomalous propagation defined as super refraction, sub refraction and ducting.

Super refraction is a situation in which the vertical distributions of temperature, humidity and pressure cause radio waves to bend more toward the earth than under normal conditions, i.e. when $-157\ N\text{-units/km} < dN/dh < -40\ N$ units/km.

Sub-refractive conditions cause radio waves to be refracted less than normal and therefore upward and away from the earth's surface, i.e. when $dN/dh > -40$ N-units/km.

Trapping or ducting occurs when meteorological conditions are such that the vertical gradient is less than -157 N-units/km, i.e. if $dN/dh < -157$ N-units/km.

3. Data acquisition

The data used for this work were obtained using the Davis Wireless Vantage Pro 2 Plus. The instrument was attached to a mast of the Nigerian Television Authority (N.T.A) situated in Maitunbi area of Minna, Niger State. The equipment set-up consists of the integrated sensor suite (ISS) which houses the sensors, the sensor interface module (SIM), the console and the computer through which the stored data are downloaded. These sensors measure atmospheric variables of pressure, temperature, relative humidity, UV index, solar radiation among others. Recordings were made at 30minutes interval and the data are stored in a data logger attached to the console The instruments are positioned near the ground level and at 100 m level. The analyzed data were for a period of 12 months from January 2008 to December 2008.

4. Results and Discussion

The *in-situ* measurement of the meteorological parameters covers both climatic seasons (the dry and wet seasons) occurring in Minna. The dry season period commences from November to March while the wet season period is usually from April to October every year.

4.1 Diurnal variation of surface refractivity

The mean hourly values of refractivity at both levels (surface and 100 m) for a typical dry season month are shown in Fig.1. Peak values of 282 *N*-Units for ground level and 281 *N*-Units for 100 m occur in the midnight and thereafter begin to decrease until a minimum value of 279 *N*-Units for ground at 1000hours (10am) and 278 *N*-Units for 100 m at 1300hrs (1pm) is reached. Refractivity values begin to increase again towards the evening and midnight hours. The mid-day minimum may be attributed to the combined effect of high temperatures and low humidity that reduces the moisture content of the atmosphere during this period of the year while the midnight peak is as a result of increased surface moisture at night. In comparison with a typical wet season month. using August (Fig. 2) as an example, it is observed that there is relatively little change in *N* from morning till afternoon hours. Also, refractivity values are higher with average value of 368 N-units/km for surface level while the average values for 100 m level oscillate between 362 N-units and 364 N-units. This pattern is exhibited in most of the remaining wet season months

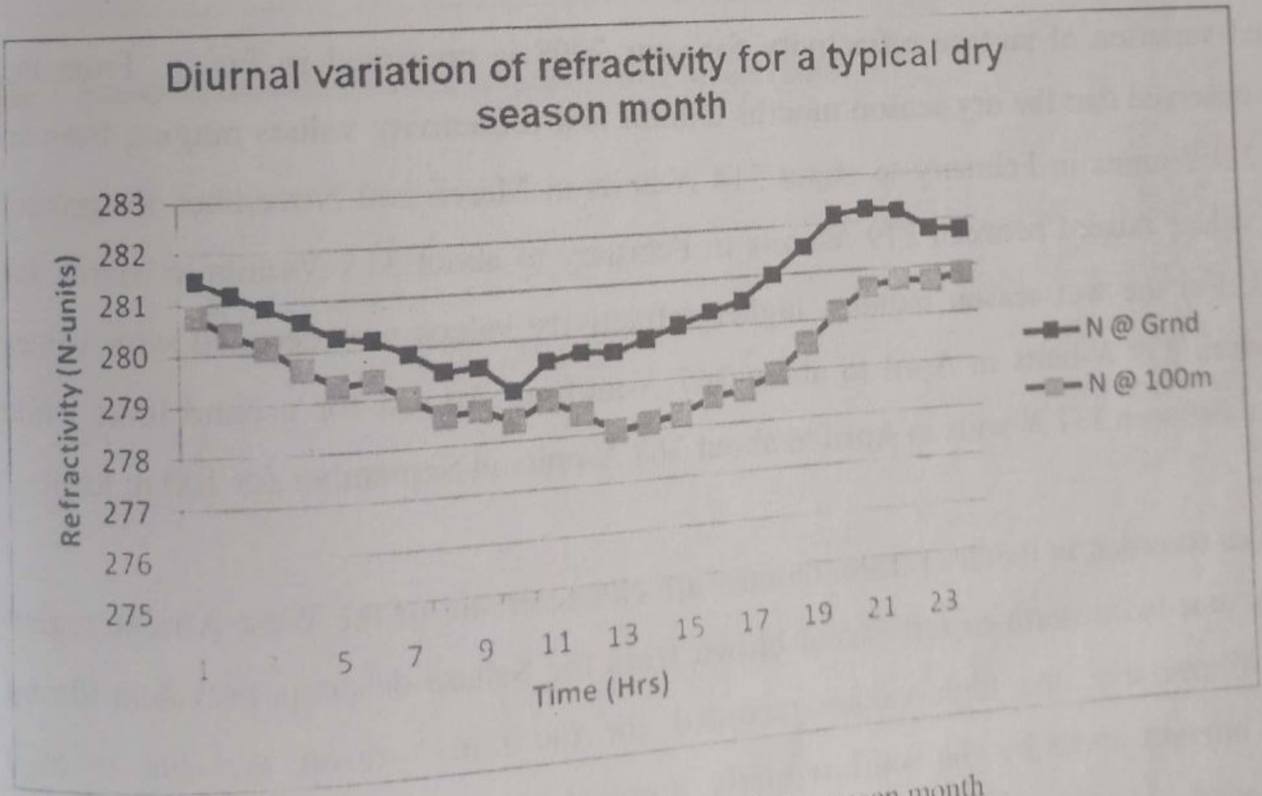

Fig. 1. Mean diurnal variation of *N* in Minna for a typical dry season month

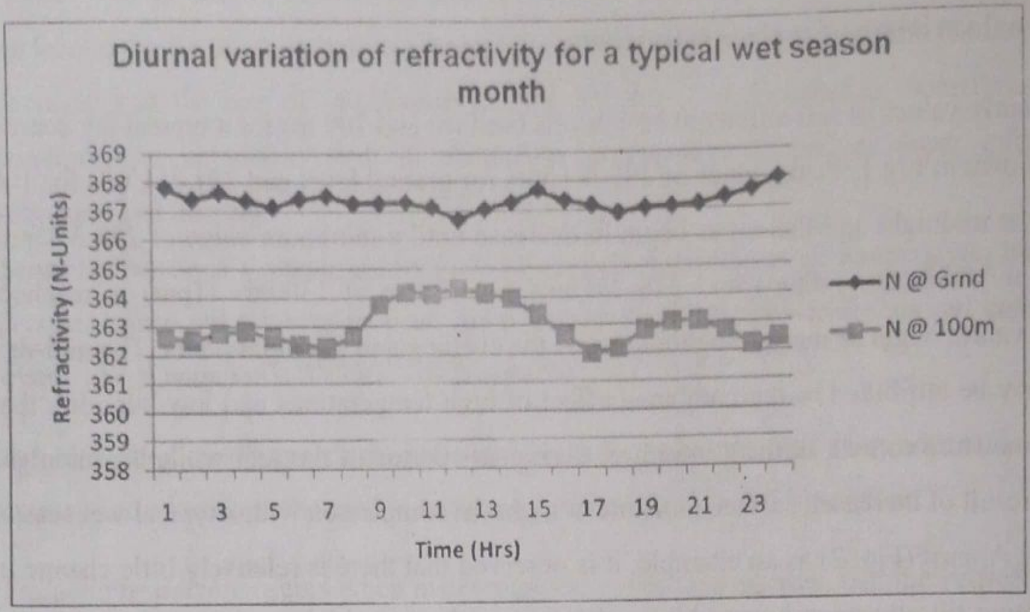

Fig. 2. Mean diurnal variation of *N* in Minna for a typical wet Season Month

4. 2 Seasonal variation of refractivity

The seasonal variation of surface refractivity for year 2008 is presented in Fig. 3. From the figure, it is observed that the dry season months exhibit low refractivity values ranging from an average of 281 *N*-units in February to about 314 *N*-units in March and November for ground level while values ranged between 279 *N*-units in February to about 315 *N*-units in March for 100 m level. For the wet season months, higher refractivity values are recorded with values ranging between 339 *N*-units in April to about 367 *N*-units in August for ground level while values ranged between 337 *N*-units in April to about 368 *N*-units in September for 100 m level.

The low values recorded in the dry season months are characteristic of the West African region when the dry dust-laden north-easterly wind blown from the Sahara desert is prevalent during this period. Conversely, the high values recorded for the rainy season are due to high precipitation brought about by the south-westerly, tropical air mass on to the sub-continent during the period. Also, in order to investigate the effect of climate change on refractivity variation over the past years in Minna, surface meteorological parameters were extracted from radiosonde data and used to calculate refractivity. The result shows that average refractivity values for all the months (except December) of 1983 were higher than those of 2008, obviously because of increased solar insolation as a result of global warming, thereby making the atmosphere over Minna less saturated with water vapour molecules (Fig.4).

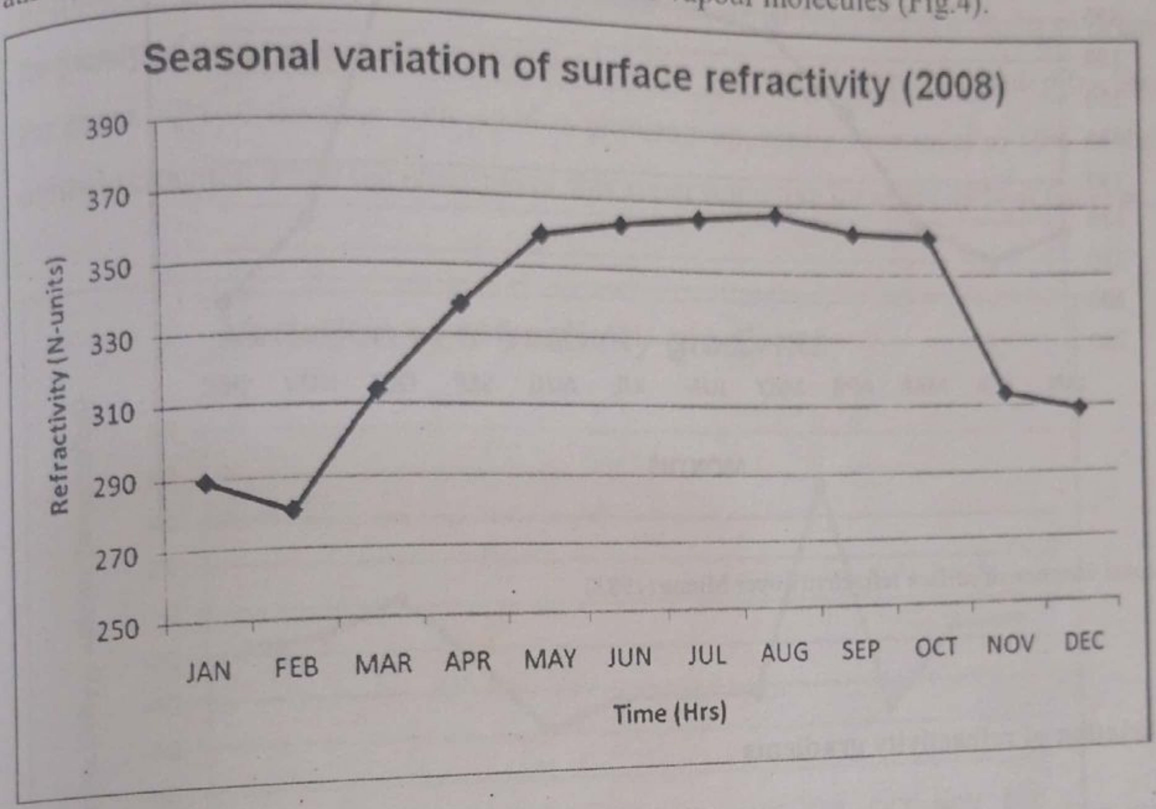

Fig. 3. Seasonal variation of surface refractivity over Minna (2008)

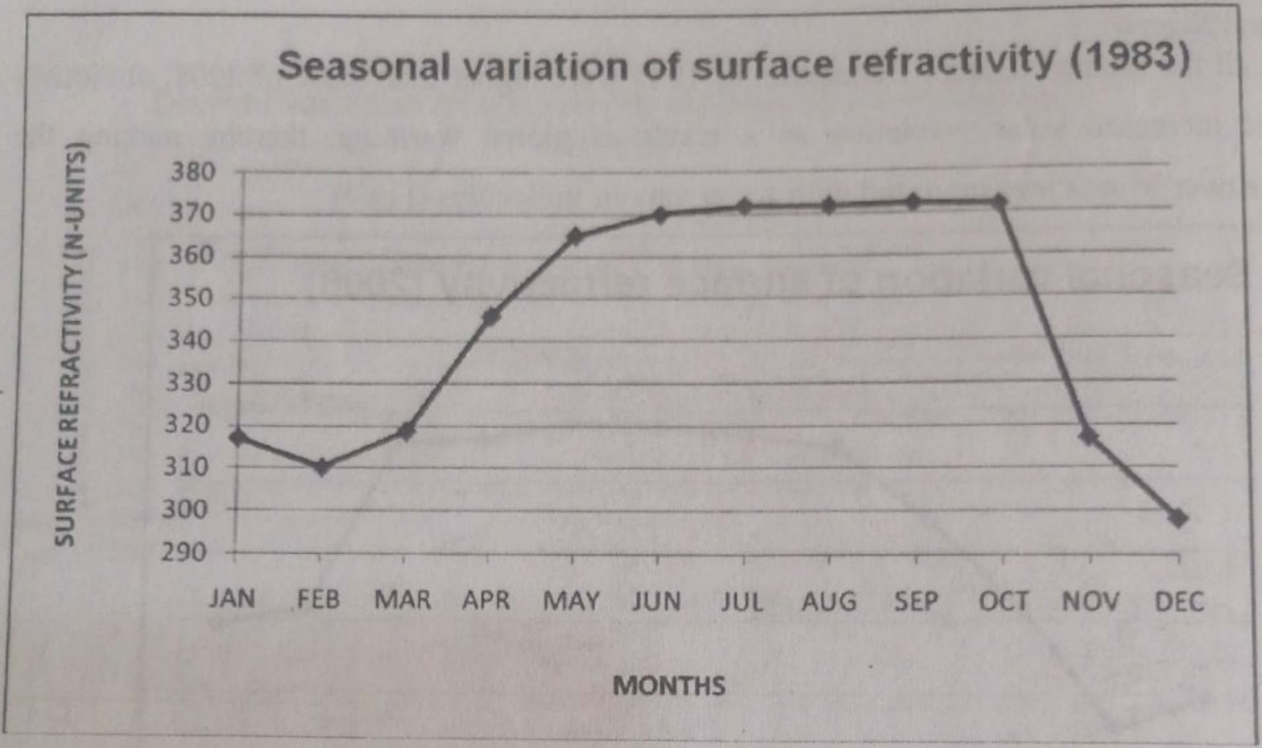

Fig. 4. Seasonal variation of surface refractivity over Minna (1983)

4. 3 Variation of refractivity gradients

Refractivity gradients at 100 m were determined from the calculated values of refractivities at both levels. The result obtained for the average monthly records is presented in Fig. 5. It is observed that sub refractive condition is prevalent during the dry season months including April. Values ranged from -17 N-units/km in January to 4 N-units/km in March while the atmosphere is super-refractive during the wet season with values ranging from -59 N-units/km in May to -52 N-units/km in October. The month of September was sub refractive because of abnormal atmospheric conditions such as temperature inversion in some days of the month (Table 2). The table clearly shows that temperature increases with increasing height. There was no occurrence of ducting.

4.3.1 Cumulative frequency distribution of gradients

Refractivity gradients were categorized at intervals of 10 N-units/km in order to determine their frequency of occurrence. This is illustrated in Fig. 6. It was observed that sub refraction occurred for about 50% of the time with positive gradients appearing occasionally, 10% of the time was normal refraction while the atmosphere was super refractive for about 40% of the time.

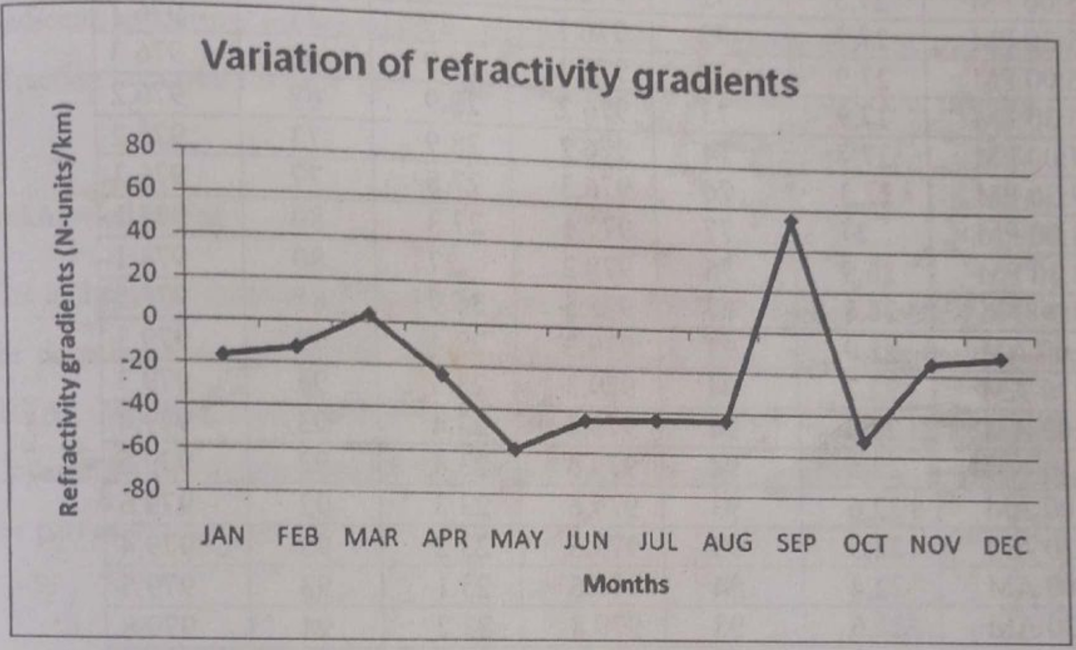

Fig. 5. Seasonal variation of refractivity gradients

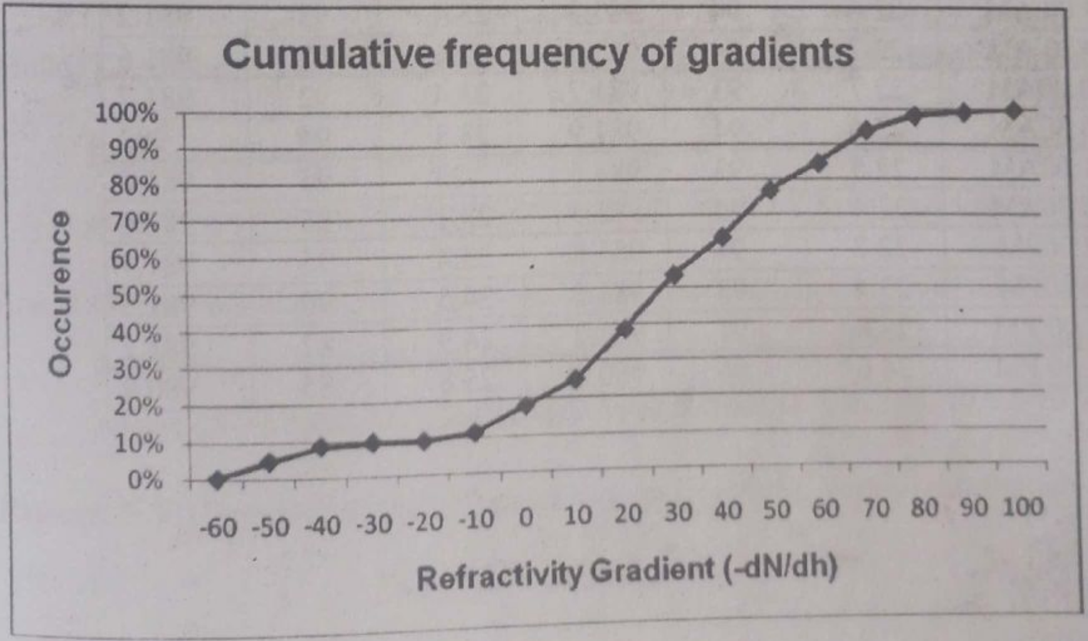

Fig.6. Cumulative frequency of refractivity gradients

Table 2: Typical days of observed temperature inversion at 100m level.

Date	Time	Surface			100m		
		Temp	Hum	Pressure	Temp	Hum	Pressure
9/1/2008	2:30 PM	26.4	77	978.7	28.3	74	978.8
9/1/2008	3:00 PM	26.8	75	978.1	28.7	73	978.1
9/1/2008	3:30 PM	27.1	73	977.4	29.3	69	977.5
9/1/2008	4:00 PM	27.5	71	976.9	29.4	68	976.9
9/1/2008	4:30 PM	27.4	73	976.6	28.8	72	976.5
9/1/2008	5:00 PM	27.5	72	976.2	28.6	72	976.2
9/1/2008	5:30 PM	27.7	72	976.1	29	71	976.1
9/1/2008	6:00 PM	27.9	72	976.1	29.9	68	976.3
9/1/2008	6:30 PM	27.9	73	976.2	29.9	68	976.2
9/1/2008	7:00 PM	27.7	74	976.2	28.9	73	976.2
9/1/2008	7:30 PM	27.3	76	976.3	27.8	77	976.3
9/1/2008	8:00 PM	27	77	977.1	27.3	80	977.1
9/1/2008	8:30 PM	26.9	76	978.2	27	80	978.1
9/1/2008	9:00 PM	26.8	77	978.5	26.9	81	978.5
9/2/2008	4:00 AM	22.9	93	979.3	23.4	92	979.3
9/2/2008	4:30 AM	22.7	94	979.3	23.5	93	979.3
9/2/2008	5:00 AM	22.6	94	979.4	23.4	93	979.4
9/2/2008	5:30 AM	22.5	94	979.6	23.4	92	979.5
9/2/2008	6:00 AM	22.6	93	979.6	23.3	92	979.6
9/2/2008	6:30 AM	22.5	93	979.5	23.2	93	979.4
9/2/2008	7:00 AM	22.4	94	979.6	23.1	93	979.5
9/2/2008	7:30 AM	22.6	93	979.8	23.2	94	979.8
9/2/2008	8:00 AM	22.5	93	980.6	23.2	93	980.4
9/2/2008	8:30 AM	22.5	94	980.9	23.3	93	980.8
9/2/2008	9:00 AM	22.6	94	981.3	23.4	93	981.2
9/2/2008	9:30 AM	22.7	94	981.6	23.6	92	981.6
9/2/2008	10:00AM	22.7	93	981.7	23.4	92	981.7
9/2/2008	10:30AM	22.4	94	981.9	23.3	94	982
9/2/2008	11:00AM	22.5	93	981.5	23	95	981.6
9/2/2008	11:30AM	22.4	94	981.5	23.1	95	981.6
9/2/2008	12:00PM	22.7	94	981.8	23.4	95	981.9
9/2/2008	12:30PM	23.4	93	981.5	24.5	90	981.5
9/2/2008	1:00 PM	23.8	91	981.2	24.9	87	981.2
9/2/2008	1:30 PM	24.6	86	980.8	25.8	85	980.9

5. Conclusion

From this analysis, it has been shown that refractivity value is generally low during the dry season and generally high during the rainy season at both levels. Refractivity gradients were also calculated and values for dry season months ranged from -17 *N*-units/km in January to 4 *N*-units/km in March while the values for wet season months ranged from -59 *N*-units/km in May to -52 *N*-units/km in October. The Cumulative frequency distribution of annual average gradients shows that the atmosphere over Minna was sub refractive for about 50% of the time with positive gradients appearing occasionally, super refractive for about 40% of the time while normal refraction occurred for only 10% of the time. There was no occurrence of ducting.

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References

Afullo, T.J., Adongo, M.O., Motsoela, T.,(1998). Seasonal variation of radio refractivity in Botswana. *Proceedings of URSI commission F open symposium on climatic parameters in radiowave propagation prediction*, 27-29 April, 1998, Ottawa, Canada, pp 196.

Aro, T.O. and Willoughby A.A., (1992). Some characteristics of radio refractive index in the first kilometer of a tropical troposphere. *Proceedings of Wave propagation and remote sensing*, 8-12 June, 1992, Ravenscar North Yorkshire, U.K., pp. 10.5.1-10.5.14.

Batueva, E.V., Darizhapov, D.D., Tarbazheeva, O.L., (1998). Vertical distributions of radio meteorological parameters of troposphere of far East of Russia. *Proceedings of the Eighth URSI commission F Triennial open symposium,* 22-25 September, 1998, Aviero, Portugal, pp 196-199.

Bean, B.R. and Dutton, E.J. (1968). *Radio Meteorology.* New York., 180 Varick Street, Dover Publications inc pp 1.

Hall, H.P.M. (1979). *Effects of the troposphere on radio communication,* U.K. & U.S, Peter Peregrins Ltd, pp 1, 15, 22, 26.

Isaakidis S. and Xenos T., (2004). Parabolic Equation Solution of Tropospheric wave propagation using FEM. *Progress in Electromagnetics Research,* PIER 49, 257 – 271

ITU-R, (1999). The radio refractive index: Its formula and refractivity data. *Recommendation ITU-R* pp .453-7.

ITU-R, (2003). The radio refractive index: Its formula and refractivity data. *Recommendation ITU-R* pp .453-9.

Kolawole, L.B. and Owonubi, J.J., (1982). The surface radio refractivity over Africa, Nigeria. *Journal of Science*, vol. 16, Nos. 1 & 2, pp. 441-454.

Mitra, A.P., Reddy, B.M., Radicella, S.M., Oyinloye, J.O. and Feng, S., (1987). *Handbook on radio propagation for tropical and sub-tropical countries*, URSI committee on developing countries, UNESCO subvention, pp. 59-83 .

Owolabi, I.E. and Williams, V.A. (1970). Surface radio refractivity patterns in Nigeria and the Southern Cameroons. *Journal of West African Science Association*, 15, pp. 3-7.

Willoughby, A.A., Aro, T.O. and Owolabi, I.E., (2001). Seasonal variations of radio refractivity gradients in Nigeria. *Journal. of Atmospheric and Solar-Terrestrial Physics*, 64, 418.