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SEASONAL VARIATIONS OF RADIO REFRACTIVE INDEX GRADIENTS OVER MINNA IN NORTH CENTRAL NIGERIA

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Abstract

Variations of radio refractivity with height up to 10 km atmospheric layer above ground over Minna (9° 37"N, 6° 30"E) have been evaluated. Five years Radiosonde data was used. The refractivity-altitude variation over Minna has also been compared with those of four low latitude stations: Addis Ababa, Ethiopia (9° 01'N); Khartoum, Sudan (15° 35'N); Mumbai, India (18° 57'N) and Nampula, Mozambique (15° 06'S). From the values of refractive index gradients computed, subrefractive condition was observed during the dry season while superrefractive condition was observed during the wet season periods over Minna. Also, an average value of 1.41 was calculated for the effective earth radius factor of the region.

Key words: Refractivity, Refractive index gradient, subrefraction, superrefraction.

1.0 Introduction

The troposphere is the lower part of the atmosphere, in which temperature generally decreases with height. It extends from ground level to an altitude of about 9 km at the earth's poles and 17 km at the equator [1]. The troposphere contains over 80% of the mass of the atmosphere, along with nearly all of the water vapour.

The earth's weather system is confined to the troposphere and the fluctuations in weather parameters like temperature, pressure and humidity cause the refractive index of the air in this layer to vary from one point to another. It is in this context that the troposphere assumes a vital role in the propagation of radiowaves at VHF (30-300 MHz) and UHF (300-3000 MHz) frequencies. The meteorological conditions therefore influence the manner in which radiowave propagation occurs in the troposphere both on a spatial and temporal scale [2].

A significant property of the refractive index used in studying the effect of the troposphere on radio propagation is its vertical gradient. The variations in the vertical profile of the refractive index and its gradients are responsible for the change in the trajectory of radio rays in the troposphere [3].

2.0 Data Acquisition

Actual measurements of pressure, temperature and relative humidity were obtained by means of a radiosonde. Daily radiosonde ascents over Minna station were made at 1200hours local time and the data collected was for a period of five years. The data considered in this study is restricted to the period 1979 to 1983.

This is because 1983 was the last time radiosonde ascents were made over Minna.

3.0 Theoretical Background

The radio refractive index n of a parcel of air is defined as the ratio of the propagation velocity of an electromagnetic radiation in vacuum to that of air. The refractive index at the earth surface is slightly greater than unity and gradually decreases towards unity with increase in altitude. At the earth surface, radio refractive index is about 1.00035. In order to have an easier number to handle, the radio refractivity is defined by [4] as

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

So, for example, when n = 1.000350, N = 350. N is strictly the refractivity, but more usually referred to as refractive index.

The radio refractive index of clear air for frequencies up to about 30 GHz is generally given by the formula [4]

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

where P is the atmospheric pressure in millibars (mb), e is the water vapour pressure in mb and T is the absolute temperature in Kelvin.

Expanding equation (2) yields

$$N = \frac{77.6P}{T} + \frac{3.73 \times 10^5 e}{T^2} \tag{3}$$

The first and second terms represent the dry (N_{dry}) and wet (N_{wet}) components of refractivity respectively [1].

The vapour pressure, e is estimated from

$$e = (R.H \; x \; e_s)/100 \tag{4}$$

where R.H is the relative humidity and e_S is the saturated vapour pressure.

e_S is calculated from

$$e_s = 6.11 \exp\left[(19.7t)/(t + 273)\right] \tag{5}$$

t is the temperature in °C.

3.1 The Refractive index Gradient $\left(\frac{dN}{dh}\right)$

The refractive index gradient is the rate of change of N with altitude. The bending of radio rays is caused by changes in the lapse rate of N. Gradients are either obtained directly from refractometers or computed from radiosonde data.

The radio refractive index gradient, $\left(\frac{dN}{dh}\right)$ is calculated from [5]

$$\left(\frac{dN}{dh}\right) = \frac{N_1 - N_S}{h_1 - h_S}$$

(6)

where N_1 is the radio refractivity at a height of 1 km above the surface of the Earth, N_S is the surface refractivity, h_1 is height of 1 km and h_S is the surface height above sea level.

3.2 The Effective Earth Radius Factor

While dealing with radio propagation profiles, it is customary to replace curved radio rays with linear rays for the purpose of geometric simplicity. To account for drawing radio rays as straight lines, we must therefore increase the radius of the earth. The radius of this virtual sphere is known as the effective earth radius and it is approximately equal to 4/3 the true radius of the earth (i.e. roughly 8500 km) [6, 7].

Under the assumption of a constant refractivity gradient, the radio wave is an arc of a circle r, related to the refractive index n, by:

$$\frac{1}{r} = -\frac{dn}{dh}$$

(7)

where h is the height above the earth's surface in the same units as r. The effective earth's radius a_e, due to the change in refractive index is given by [8]

$$\frac{1}{a_e} = \frac{1}{a} - \frac{1}{r} = \frac{1}{a} + \frac{dn}{dh}$$

(8)

where a is the earth's radius (6.37×10^3 km). If the effective earth's radius a_e, is given by:

$$a_e = ka$$

(9)

then the k-factor, or the effective earth's radius factor is given by [8]

$$k = \frac{a_e}{a} = \frac{1}{(1+a\frac{dn}{dh})} = \frac{1}{(1+a\frac{dN}{dh}10^{-6})}$$

(10)

Substituting the median value of dN/dh (i.e. -40N/km) for temperate regions into equation (10) gives k = 1.33. The significance of the parameter k is that it permits the simplification of practical problems encountered in tropospheric communication and radio propagation engineering. For example it is useful in the calculation of the distance to the radio horizon d, of a radio ray leaving an antenna of height h metres, i.e.

$$d = \sqrt{(2a_e h)}$$

(11)

or

$$d = \sqrt{(2kah)}$$

(12)

In terms of atmospheric refraction, the three classes are as follows

Subrefraction: $\frac{dN}{dh} > -40$ or $\frac{4}{3} < k < 0$

Superrefraction: $-157 < \frac{dN}{dh} < -40$ or $0 < k < \frac{4}{3}$

Ducting: $\frac{dN}{dh} < -157$ or $k < 0$

4.0 Results and Discussion

4.1 Variation of Refractivity with Altitude

Average refractivity-altitude variation over Minna (9°′ 37"N, 6° 30"E) for some years of 1979-1983 are shown in Figs. 1a-d. The differences in variation between profiles of the dry and wet season months are revealed in the N-h curves. Refractivity values are observed to be high in the wet season months of April to October as a result of high precipitation and high moisture content recorded in those months. Surface values ranged between 359 N-units in April to 370 N-units in October. At a height of 1 km, values ranged between 337 N-units to 351 N-units while at a height of 2 km, values ranged between 301 N-units to 273 N-units. In comparison, the values obtained in the dry season months of November to March are observed to be lower. For these months, surface values ranged between 304 N-units in December to 326 N-units in March. At a height of 1 km, values ranged between 300 N-units to 310 N-units while at a height of 2 km, values ranged between 251 N-units to 263 N-units. This trend of refractivity decrease with altitude continues up to the top of the troposphere because the three components of refractivity in equation (2) all decrease with increasing altitude. This difference is clearly noticeable up to a height of 3km above ground. This is because up to this level, refractivity values are highly variable particularly in the dry season as a result of the interplay between overlying tropical continental (cT) and residuals of the tropical maritime (mT) during this period.

A mean of five years refractive index values for the month of May over Minna was calculated and plotted against the tropospheric altitude range of 0-10km. This was compared with the refractive-altitude profile of some low latitude stations for the same month (Fig. 2a): Addis Ababa, Ethiopia (9° 01'N); Mumbai, India (18° 57'N); Nampula, Mozambique (15° 06'S) and Khartoum, Sudan (15° 35'N). It was observed that Minna displayed a close initial gradient profile with Mumbai indicating that both regions have similar weather variation during this month. Mumbai is located south of the Tropic of Cancer but north of the equator and has small seasonal temperature fluctuations. In May, the average low temperature is 27°C and the average high temperature is 33°C. Mumbai also has high humidity, with an annual average of 87 percent [9]. This temperature range is very similar to that of Minna which has an average low temperature of 28°C and an average high temperature of 34°C in the same month of May.

4.2 Refractive Index Gradients and Effective Earth Radius Factor

The mean monthly refractive index gradient, $\frac{dN}{dh}$ over Minna for the five years period was calculated (Fig.2b). It was observed that values ranged from -26 N-units/Km to -28 N-units/Km in the dry season months of January to March while it varied from -36 N-units/Km to -48 N-units/Km in the wet season months of April to September 1980. Values of dry season months of 1981 ranged from -27 N-units/Km to -32 N-units/Km while the wet season values ranged from -28 N-units/Km in April to -42 N-units/Km in August. For 1983, dry months values ranged between -28 N-units/Km to -38 N-units/Km while wet season months values ranged from -33 N-units/Km to -51 N-units/Km. These values obtained showed that the atmosphere was subrefractive during the dry season periods of each year and superrefractive during the wet season periods.

The total mean value of $\frac{dN}{dh}$ for each year was used to also calculate K, the effective earth radius factor for the region. The total average values of K deduced for the five years period was found to be lower in the dry season months with a value range of 1.28 in February to 1.36 in November while values were higher in the wet season months with value range of 1.36 in April to 1.57 in August. *A total average of 1.41* was calculated for both seasons in the five years period (Fig. 2c).

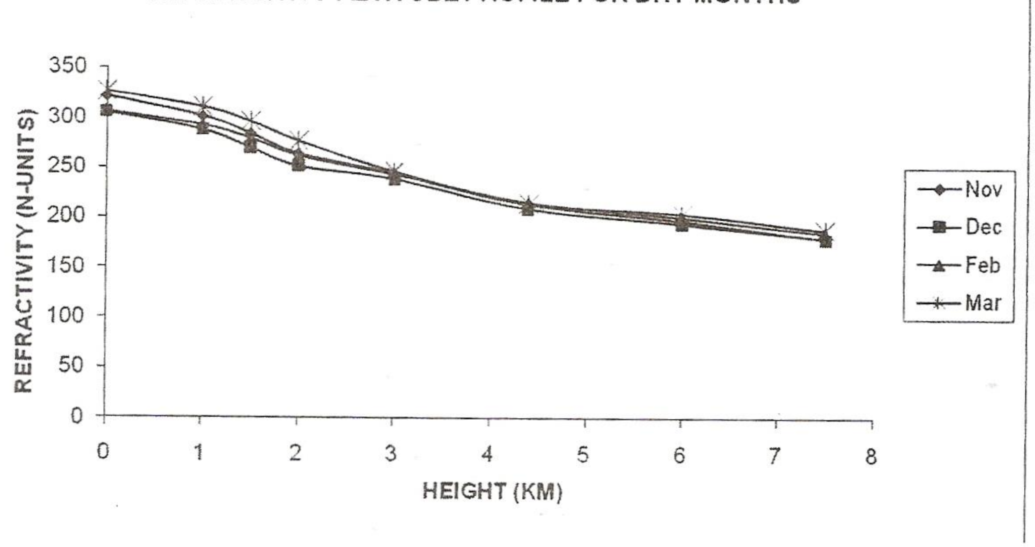

Fig.1a Mean refractivity-altitude profile for the dry season months of 1982

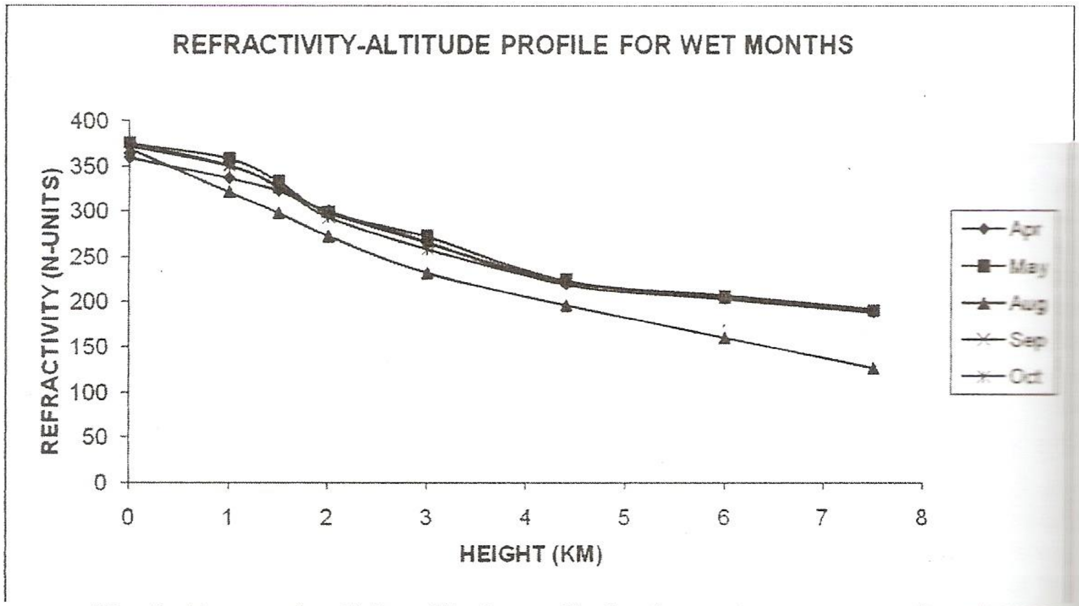

Fig.1b Mean refractivity-altitude profile for the wet season months of 1982

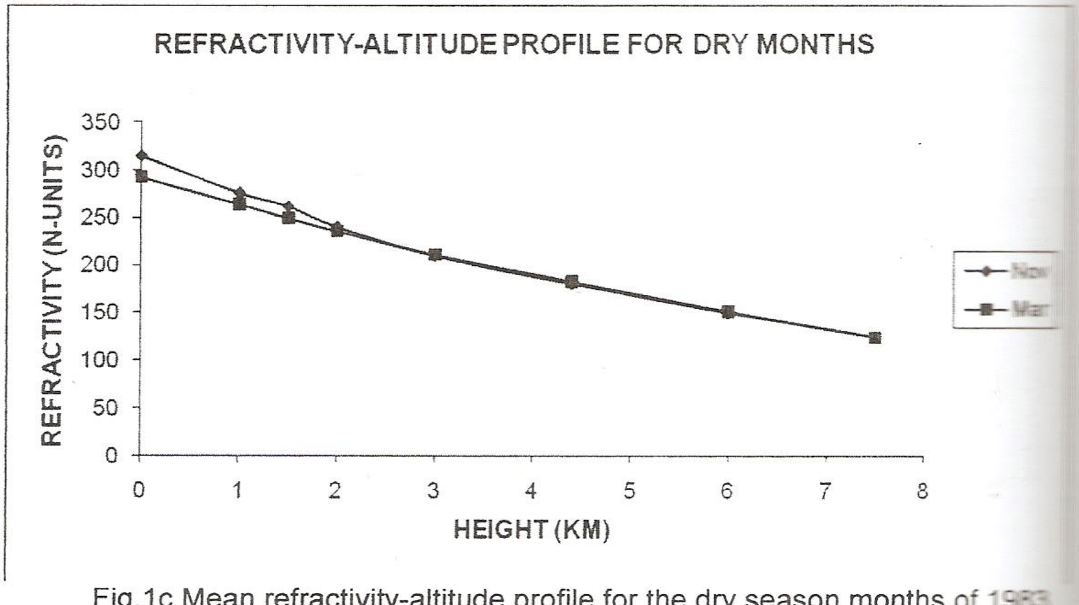

Fig.1c Mean refractivity-altitude profile for the dry season months of 1983

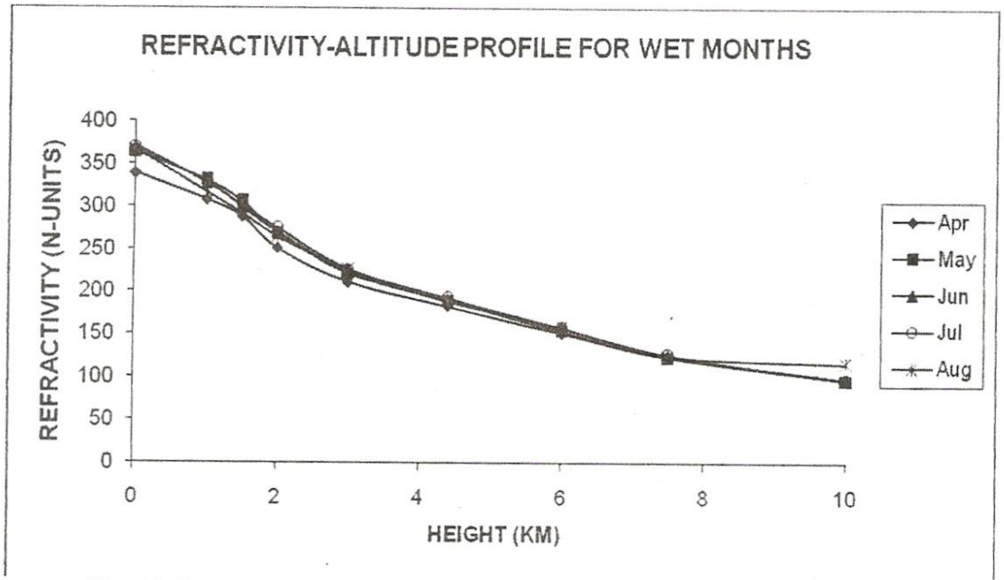

Fig.1d Mean refractivity-altitude profile for the wet season months of 1983

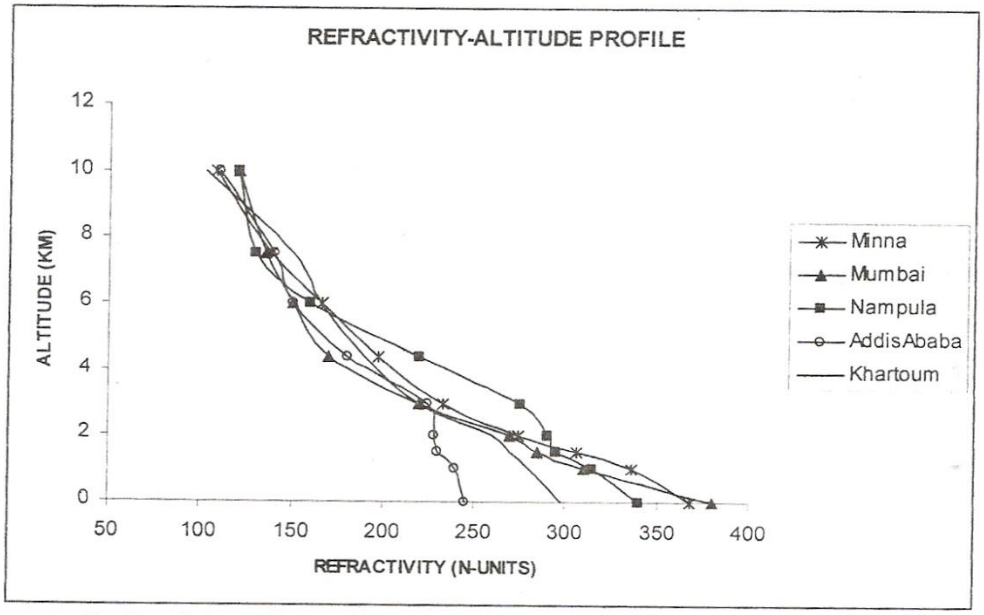

Fig.2a. Comparison of average Radio Refractivity-Altitude profile for the month of May over Minna with some low latitude stations.

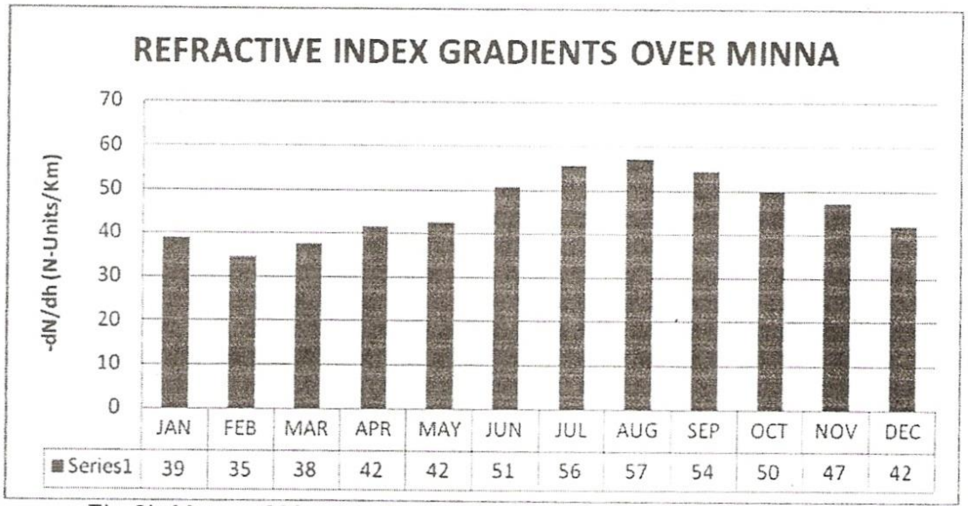

Fig.2b Mean of Monthly Refractive index Gradient from 1979-1983

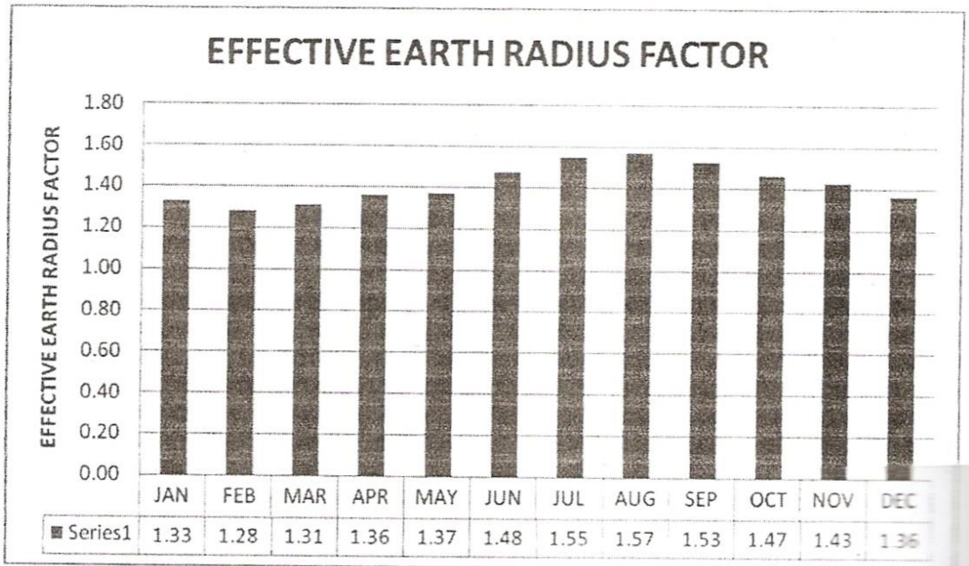

Fig.2c Mean of Monthly Effective Earth Radius Factor from 1979-1983

5.0 Conclusion

The radio refractivity profile over Minna showed that refractivity values decreased with increasing altitude and values for the wet season months were higher than values for the dry season months. The wet season values ranged from 325 N-units to 370 N-units while the dry season values ranged from 290N-units to 315 N-units. From the profile of Refractivity-Altitude plotted, it was observed that Minna displayed a close initial gradient with Mumbai indicating that both regions have similar weather variation. The atmosphere over Minna was observed to be subrefractive during the dry season with values ranging from -34N-Units/km to -38N-Units/km and superrefractive during the wet season with values ranging from -41N-Units/km to -57N-Units/km. A total average of 1.41 was calculated for K, the effective earth radius factor for the region. It is believed that these results obtained have provided the necessary and useful information needed for microwave communication designers and radio meteorologists

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