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Variations of Surface Radio Refractivity and Radio Refractive Index Gradients in the sub-Sahel

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Abstract

Monthly variations of radio refractive index near the ground surface have been computed for a period of five years from 2000 to 2004 over Ilorin (8° 32"N, 4° 34"E). The data used was obtained from the University of Ilorin atmospheric observatory operating under the radiometric network of the Baseline Surface Radiation Network (BSRN). Also, seasonal variations of radio refractivity with height of up to 10 km atmospheric layer above ground over Minna (9° 37''N, 6° 30''E) have been evaluated. The data used here are those obtained from daily radiosonde ascents made at 1200hrs local time for a period of five years from 1979 to 1983. The refractivity-altitude variation over Minna have been plotted with those of four other low latitude stations and an equation of the form $N = N_S \exp(-0.11h)$ has also been deduced to predict values of refractivity, N for these stations up to a height, h of about 2 km above ground, for a given surface refractivity, N_S. The values of refractive index gradients computed showed that the atmosphere over Minna was subrefractive during the dry season and superrefractive during the wet season periods of the years.

Key words: Refractivity, refractive index gradients

1 Introduction

Changes of temperature, pressure and humidity, as well as clouds and rain, influence the way in which radio waves propagate from one point to another in the troposphere. This region exerts a considerable influence on radio waves at frequencies above 30 MHz (Hall, 1979). Ionization of air in the troposphere is negligible since UV radiation reaching there is negligibly small, but due to the presence of gases like oxygen and water vapour which have electric dipole moments, the troposphere has a dielectric constant and hence a refractive index (Ajayi, 1989).

An electromagnetic wave transmitted at an oblique angle undergoes a progressive refraction, curving downwards as a result of variations in pressure and temperature with altitude, and effects due to water vapour, all of which decrease with increasing altitude in the troposphere. Tropospheric radio wave propagation is to a very large extent influenced by the structure of the refractive index of the atmosphere (Willoughby, 1996).

The effect of meteorological variables of pressure, temperature, and relative humidity on radio wave propagation at UHF and microwave frequencies are analyzed from the study of radio refractive index derived from these three parameters (Bean and Dutton, 1966). Since these variables vary considerably diurnally and seasonally, especially in the tropics, quantitative knowledge of refractivity variations is required in order to be able to design reliable and efficient radio communication (terrestrial and satellite) systems. It is therefore essential to have information on hourly, daily and monthly variations of refractivity and hence fade margins of signal strength at that location (Willoughby *et al*, 2003).

2 Radio Refractivity, N

For frequencies up to about 30 GHz, the radio refractive index of clear air is generally given by the formula

$$N=\frac{77.6}{T}\left(P+\frac{4810e}{T}\right) \tag{1}$$

where P is the atmospheric pressure in mb (millibars), e is the water vapour pressure in mb and T is the absolute temperature in Kelvin. N is strictly the refractivity, but more usually referred to as refractive index.

Equation (1) may be split into two and rewritten as

$$N=\frac{77.6P}{T}+\frac{3.73\times10^{5}e}{T^{2}} \tag{2}$$

the first and second term representing the dry (N_{dry}) and wet (N_{wet}) components of refractivity respectively (Hall, 1979). While the dry term contributes about 70% to the total value of N, the wet term is responsible for a major part of the variation in N at a given location in the atmosphere.

2.1 The Refractivity Gradient $(\frac{dN}{dh})$

One of the most significant factors in the influence of radio wave propagation is the large-scale variation of refractive index with height, and the extent to which this changes with time

(Hall, 1979). The refractive index gradient is the rate of change of N with altitude. Changes in the lapse rate of N cause the curvature of radio rays. Information on the occurrence and types of gradients is required for radio path design and estimates of some propagation parameters. The measured median of the mean refractivity gradient in the first kilometer above ground in most temperate regions is about -40 N-units/km,

The change in radio refractivity, $(\frac{dN}{dh})$ is calculated from:

$$(\frac{dN}{dh}) = \frac{N_1 - N_S}{h_1 - h_S} \qquad (3)$$

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 Data Acquisition

The data used for this work was obtained from two sources. One of the sources was the University of Ilorin atmospheric observatory operating under the radiometric network of the Baseline Surface Radiation Network (BSRN). A combined Temperature-Relative humidity sensor of Model HMP35C probe was used to measure temperature and relative humidity while Pressure was measured with a CS105 analogue barometer sensor. For each instrument, there were 1440 records for every 24 hours. The data used was for a period of five years from 2000 to 2004.

The second data, a radiosonde data was obtained from 'Upper air' section of the Department of Meteorological Services, Oshodi, Lagos. Daily radiosonde ascents over Minna station was made at 1200hrs local time and the data collected was for a period of five years (1979 to 1983).

4 Results and Discussion

4.1 Variation of Surface Refractivity

The monthly variations of surface refractivity over Ilorin for some selected months of the years 2000 to 2004 have been examined and are presented in Figs.1 (a&b).

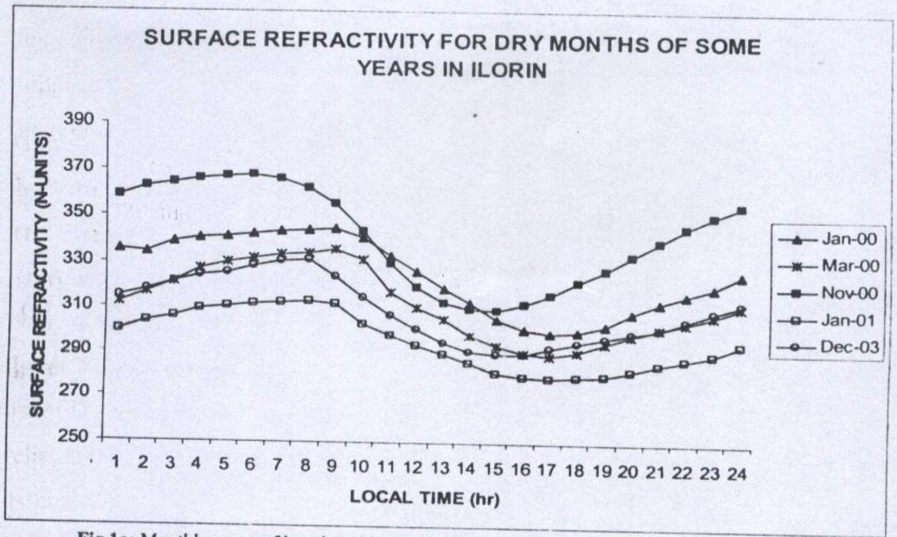

Fig.1a: Monthly mean of hourly surface refractivity for some dry months

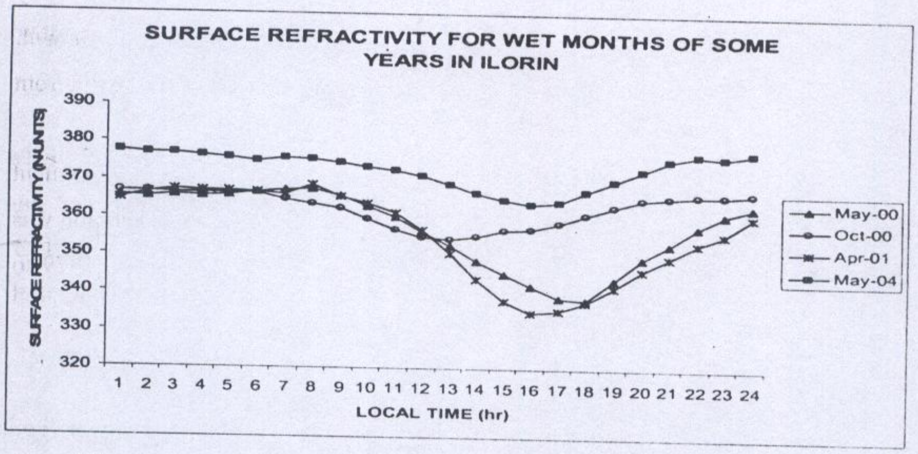

Fig.1b: Monthly mean of hourly surface refractivity for some wet months

These results were computed from hourly and diurnal average values. From the plots, it is observed that the dry season months (Fig.1a) have low refractivity values ranging from a total average of 290 N-units to about 340 N-units for the five years period. Also, during these months, it is evident that large diurnal ranges and variability of N are displayed. The factor responsible for this variability is the wet term factor given by equation (2). The data for these months reflect the strong influence of dry continental air mass prevalent during the dry season, hence pronounced diurnal ranges are observed in these months. Low humidity and high temperatures combine to make the moisture content low, and as a result, refractivity values are reduced.

Comparing the rainy season months from April to October (Fig.1b) with the plots for the dry season months, uniform refractivity values are observed. During the rainy season, refractivity values are observed to be higher than the values obtained in the dry season. These high values are attributed to extensive cloud cover and saturation of the atmosphere with larger amount of water vapour during this period. Refractivity values are found to vary between 352 N-units and 378 N-units.

Fig.1c shows the monthly average variation of surface refractivity from 2000 to 2004. It is observed that the dry months recorded lower refractivity values than the wet months. The month of February has the lowest value. It is also seen that the wet months from April to October form a plateau which begins to descend as we enter the dry month of November. The Months of June

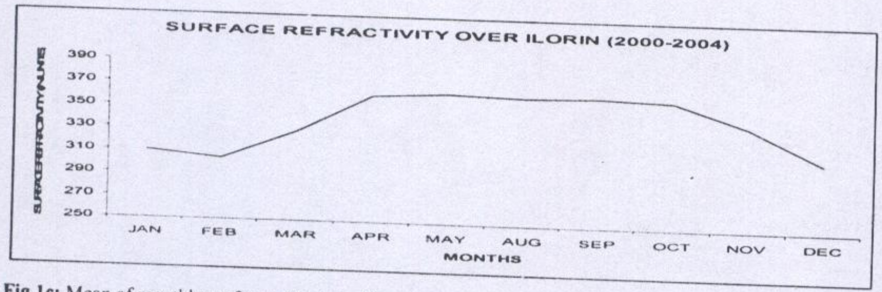

Fig.1c: Mean of monthly surface refractivity from 2000-2004

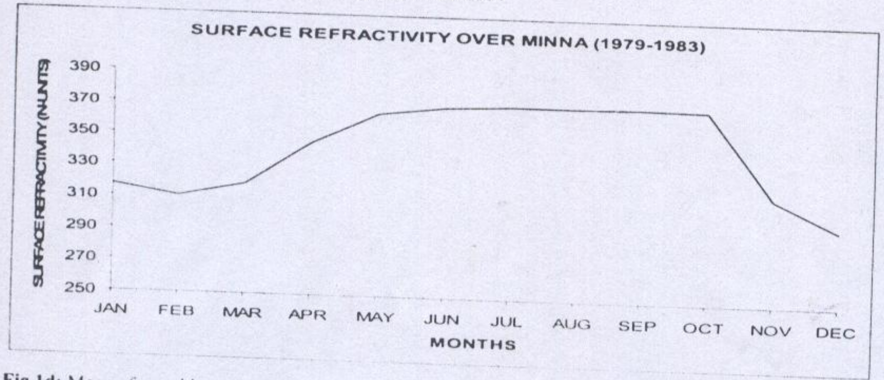

Fig.1d: Mean of monthly surface refractivity from 1979-1983

and July were not displayed because of insufficient data for their analysis. Though, radiosonde data was used for the analysis of refractivity profile over Minna, surface values of temperature, pressure and relative humidity were extracted and computed for the five years period (Fig.1d). The result obtained followed a similar trend as Ilorin station (Fig.1c).

4.2 Variation of Refractivity with Altitude

Minna (9° 37''N, 6° 30''E) is approximately 249m above sea level. Surface refractivity values vary from 290 N-units to 315 N-units in the dry season and from 325 N-units to 370 N-units in the wet season months. Profiles of average refractivity-altitude variation over Minna for selected years within 1979 and 1983 are shown in Figs. 2(a-d). The N-h curves reveal the differences in variation between profiles of the dry and wet season months. As a result of high precipitation and high moisture content recorded in the wet season months of May to October, refractivity values are observed to be higher in those months than the values obtained in the dry season months. This difference is distinct up to a height of 3km above ground. Up to this level, refractivity values are highly variable particularly in the dry season, because of the interplay between overlying tropical continental (cT) and residuals of the tropical maritime (mT) during this period. Generally, refractivity values are observed to decrease with increasing altitude.

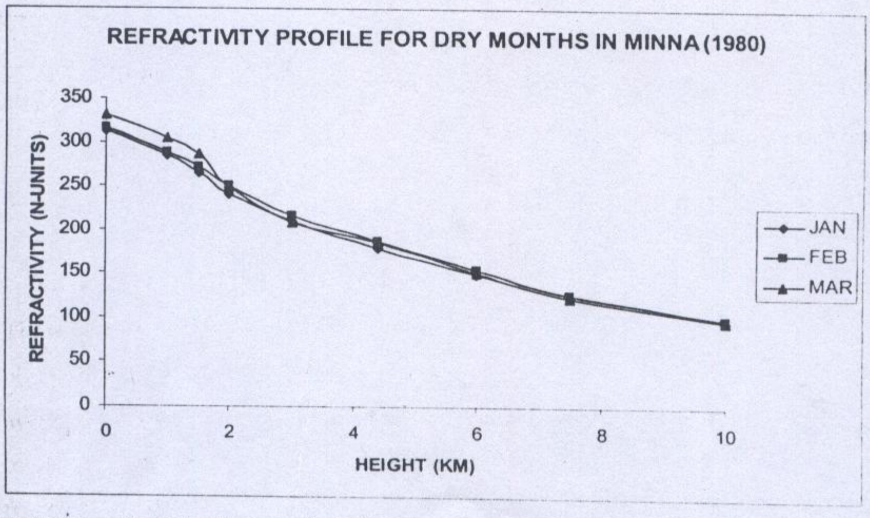

Fig.2a: Mean refractivity-altitude profile for the dry season months of 1980

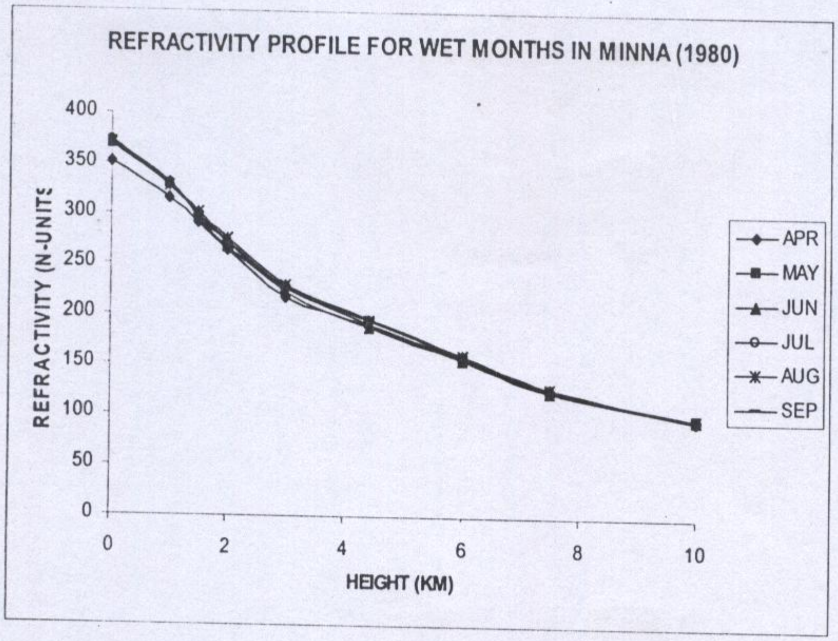

Fig.2b: Mean refractivity-altitude profile for the wet season months of 1980

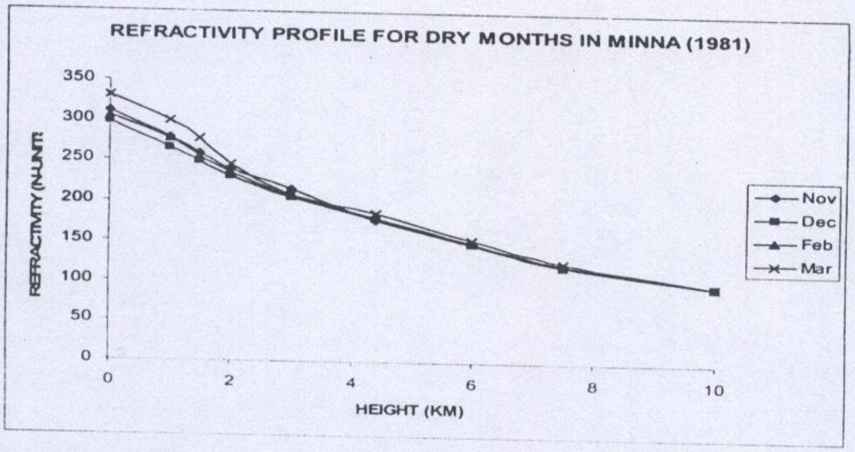

Fig.2c: Mean refractivity-altitude profile for the dry season months of 1981

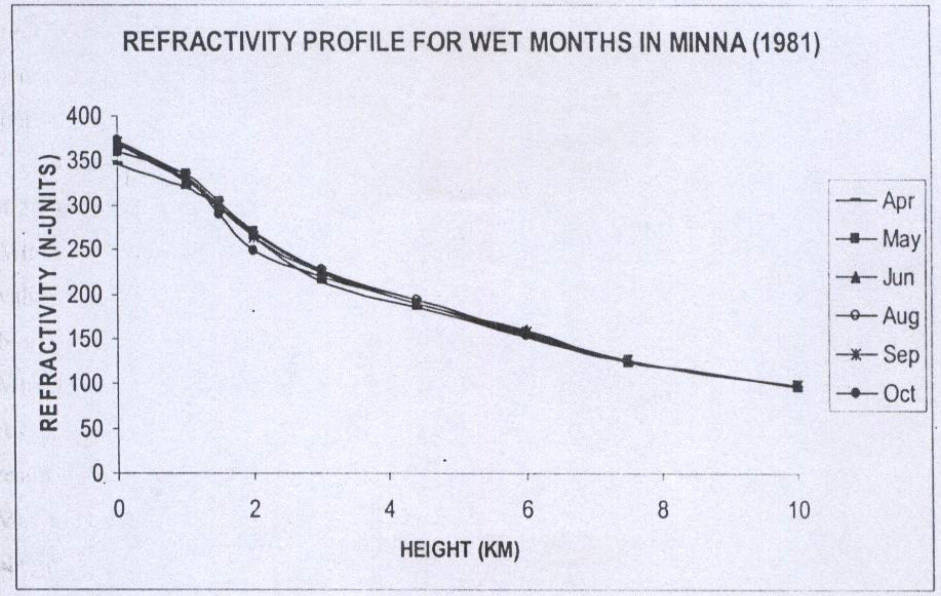

Fig.2d: Mean refractivity-altitude profile for the wet season months of 1981

An average of five years refractivity-altitude profile for the month of May over Minna was plotted along those of some 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). An equation of the form $N = N_S \exp(-0.11h)$ was also deduced to predict values of refractivity, N for these stations up to 10 km above ground for a given surface refractivity, N_S. It was observed that the equation predicted well, with a slight deviation, up to a height of 2 km above ground for the stations with the exception of Addis Ababa and Mumbai. The measured values are shown with scattered plots while the deduced values are shown with lines (Fig.2e).

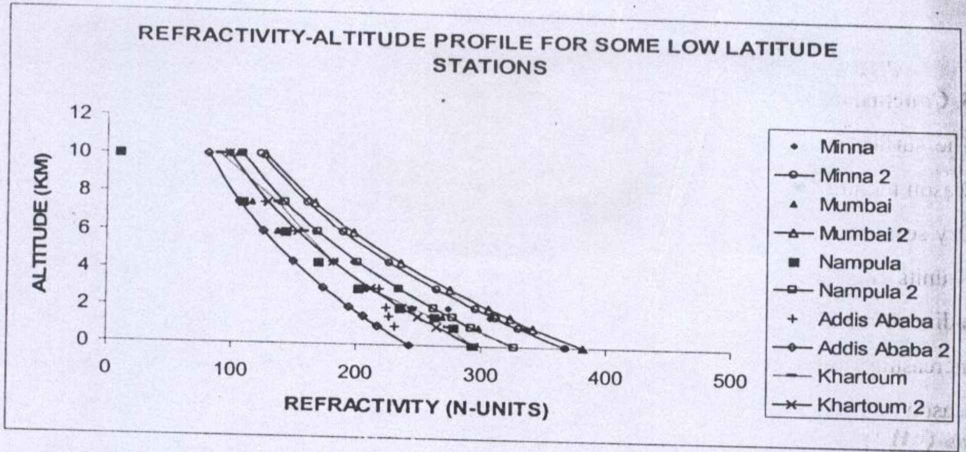

Fig.2e: Comparison of measured average Radio Refractivity profiles for the month of May with the deduced values using equation $N = N_S \exp -0.11h$.

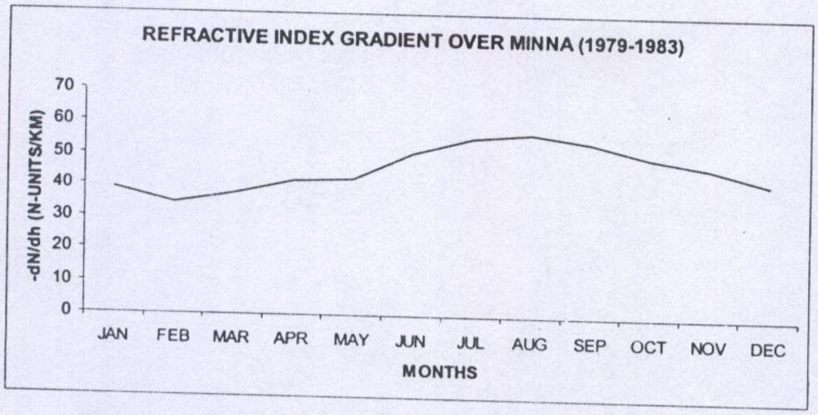

Fig. 2f: Mean of Monthly Refractive index Gradient from 1979-1983

4.3 Refractive Index Gradients

The average monthly refractive index gradient, $\frac{dN}{dh}$ from 1979 to 1983 over Minna was calculated and found to vary from -34 N-units/Km to -38 N-units/Km during the dry season periods and -41 N-units/Km to -57 N-units/Km during the wet season periods (Fig.2f). These values obtained showed that the atmosphere was subrefractive during the dry season and superrefractive during the wet season.

5. Conclusion

The surface radio refractivity over Ilorin have been found to be more variable in the dry season months from November to March than the wet season months from April to October. Dry season months also exhibited lower refractivity values ranging from 290 N-units to 340 N-units compared with the wet season months values of 352 N-units to 378 N-units. 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. 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. Also, the deduced equation, $N = N_S \exp(-0.11h)$ was able to predict values of refractivity with a slight deviation, up to a height of 2 km above ground for some low latitude stations.

Acknowledgements

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