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Diurnal and Annual Cycles of Surface Refractivity and Related Parameters in Minna, Central Nigeria

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Abstract

Radio refractivity N exerts considerable influence on radio signals at VHF and higher frequency bands. In particular, surface refractivity correlates positively with radio field strengths, and knowledge of its temporal variability is important in predicting performance of terrestrial radio networks, especially at VHF and microwave frequencies. Knowledge of the variability of the atmospheric parameters from which N derives is also important for radio propagation and other applications such as Agriculture and Tourism. Measurement of atmospheric parameters is also necessary to update past records, especially in the light of climate change. Surface refractivity values derived from values of air pressure P, temperature T and relative humidity H measured for two consecutive years (2008-2009) in Minna ($09^0 37'N$, $06^0 32'E$),Central Nigeria are statistically analysed to explore their diurnal and seasonal cycles, as well as their inter-relationships. The results reveal that surface refractivity and the related weather variables show clear diurnal and seasonal trends with discernible relationships. In particular, diurnal N values have high correlation with diurnal P values, while monthly averages of N and H are also highly correlated; and the hot weather generally experienced in the month of April in Minna may be attributed to a combination of high humidity and high temperature at surface level.

Key words: Refractivity, Temperature, Pressure, Humidity, Hourly Mean and Monthly Mean.

Introduction

The refractive index of the atmosphere is an important factor in predicting performance of terrestrial radio links. Refractive index variations of the atmosphere affect radio frequencies above 30 MHz, although these effects become significant only at frequencies greater than about

100 MHz especially in the lower atmosphere. The radio refractive index n of the troposphere deviates slightly from unity due to (1) polarisability of the constituent molecules by the incident electromagnetic field, and (2) quantum mechanical resonances at certain frequency bands. Whereas molecular polarisability is independent of frequency up to millimetre waves, molecular resonance is totally frequency dependent, and n tends to be dispersive above ~50 GHz (Bean and Dutton, 1968).

Radio refractivity N is a measure of deviation of refractive index n of air from unity which is scaled-up in parts per million to obtain more amenable figures. Thus, N is a dimensionless quantity defined as (ITU, 2003)

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

N depends on meteorological factors of pressure P (hPa), temperature T (K) and water vapour pressure e (hPa), as given by the relation (Smith and Weintraub, 1953; ITU, 2003):

$$N = 77.6/T\,(P + 4810e/T^2) \qquad (2)$$

Where T = air temperature (K)

P= air pressure (hPa)

e= water vapour pressure (hPa)

The vapour pressure is also related to the relative humidity H (%) as (ITU, 2003):

$$e = \left[\frac{He_s}{100}\right] \qquad (3)$$

e_s is the maximum (or saturated) vapour pressure at the given air temperature t °C, and may be obtained from (ITU, 2003):

$$e_s = 6.11 \exp\left[\frac{17.502t}{(t + 240.97)}\right] \qquad (4)$$

Equation (2) may be expressed in form of the dry term and the wet term given as (ITU, 2003):

$$N_{dry} = 77.6\frac{P}{T} \qquad (5)$$

and
$$N_{wet} = 4810\frac{e}{T} \tag{6}$$

Generally, P and e decrease rapidly with height while T decreases slowly with height.

Horizontal variation of refractive index is generally negligible in the lower troposphere compared to the large-scale vertical variation which has a median gradient of about -40 N/km near the surface in midlatitude and most temperate regions (Bean *et al*, 1966). However, significant deviations can arise from local or mesoscale meteorological factors, especially in the tropics (Owonubi, 1982). Decrease of n with height causes radiowaves to curve downwards, and to a degree which depends on the vertical refractivity gradient. Refractive bending causes extension of the radio horizon beyond the optical horizon. Surface radio refractivity N_s is known to have high correlation with radio field strength values (Bean and Cahoon, 1961; Hall, 1979) while the surface refractivity gradient which depends on N_s determines the refractivity condition of the atmosphere which may result in a normal, subrefractive, superrefractive or ducting layer, each of which has important influences on propagation of VHF, UHF and microwaves in the atmosphere.

Under normal atmospheric conditions, the refractive index of air decreases uniformly with height, and the surface value N_s is known to have a good positive correlation with the parameter ΔN representing the refractivity gradient in the first 1 kilometre above the surface. Lane and Bean (1963) obtained correlation coefficient of 0.70 between VHF field strength and N_s and 0.71 between VHF field strength and ΔN. Other parameters also proposed for predicting or interpreting radio data include the equivalent gradient G_e (Misme, 1960), and the potential refractive index K (Flavell and Lane 1962); while Saxton (1963) highlighted the relative merits of the parameters. However, N_s is commonly used because of the relative ease in obtaining the related surface parameters of temperature, pressure and relative humidity from many widely separated stations. Bean and Thayer (1963) showed that elevation angle errors and range errors can also be predicted from N_s values.

Thus, good knowledge of N_s as well as the diurnal and annual variability is particularly useful in planning terrestrial radio links. Knowledge of the diurnal and seasonal profiles of the atmospheric parameters related to refractivity is also useful for other applications such as Agriculture and Tourism, especially in a place like Minna which has good agricultural and tourism potentials. Diurnal variations tend to be more pronounced in summer, especially in tropical areas. Earlier efforts in this regard with respect to Nigerian stations could not explore the diurnal trend due to paucity of data. Owolabi and Williams (1970) showed that N_s in Minna has an annual range of 300-375 N-units while the seasonal trend showed that N_s rises from February to April, is steady between April and September and decreases from October to a minimum in February. The study by Kolawole (1980) revealed that reduced-to-sea-level surface refractivity N_o in Nigeria varies from about 390 in the coastal areas of South to about 280 in the northern parts of the country. This is in agreement with Adebanjo (1977) but slightly differs from Owolabi and Williams (1970) due to the elevation dependence of N_s. Oyedum and Gambo (1994) obtained similar results and a correlation coefficient of 0.73 between N_s and transhorizon VHF field strength values in Northern Nigeria; Oyedum (2005) showed that based on N_s variability, substantial climate-related differences exist between the seasonal variability of VHF field strength and radio horizon distance in two Nigerian stations of Lagos (06^0 35′N, 03^0 20′E) on the Atlantic coast and Kano (12^0 03′N,06^0 42′E) in sub-Sahara Northern Nigeria.

Oyedum *et al* (2009) showed that reduced-to-sea-level refractivity in Minna ($09^0$37′N, $06^0$32′E) has considerable diurnal and seasonal tendencies: Maximum values occur in the night while minimum values occur towards local evening; and a seasonal trend of higher values in rainy season and lower values in dry season. This seasonal trend is in agreement with other reports on Nigerian stations, including more recent efforts such as Adeyemi (2006) or Adedeji and Ajewole (2008). The cities of Lagos, Minna and Kano represent important meteorological stations in Nigeria because they were functional radiosonde stations respectively located in Southern, Central and Northern Nigeria in line with the climatic conditions in the country (see Fig. 1).

Data Collection and Analysis

Davis weather instrument Vantage Pro 2 Plus was used to monitor and log atmospheric parameters such as pressure, temperature, relative humidity, dew point, etc for two consecutive years (2008-2009). Continuous monitoring of atmospheric parameters is also informed by the need to update past records, especially in the light of climate change. The instrument was attached at surface level on the mast of the Nigerian Television Authority (NTA), Minna located in an elevated part of Minna which is at about 250 metres above mean sea level. Data monitoring was continuous, logged at 30 minutes intervals and routinely downloaded to a computer for processing and analysis. Surface refractivity N was computed from equations (1) - (4) using the associated surface weather parameters of temperature (T), pressure (P) and relative humidity (H).

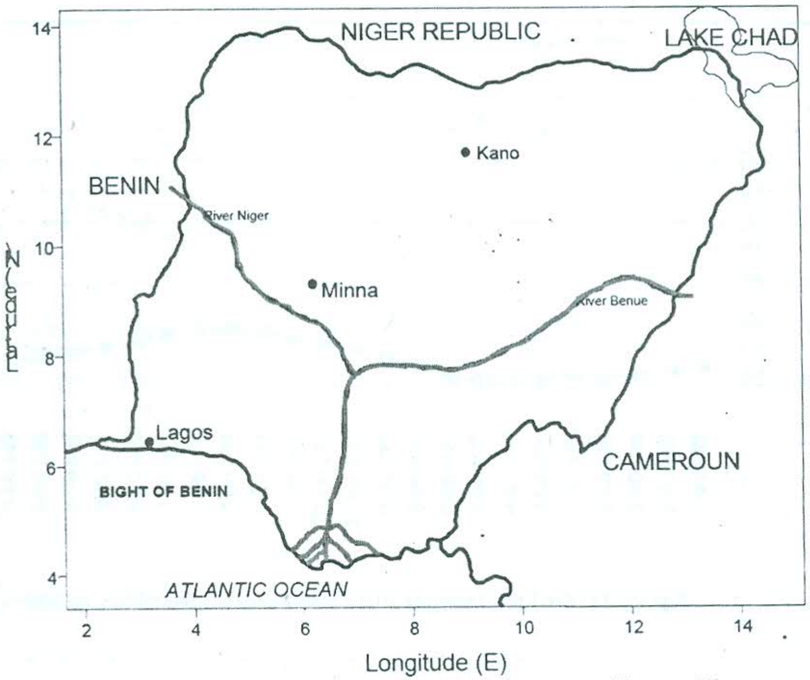

Fig. 1: Map of Nigeria Showing Relative Positions of Lagos, Minna and Kano

Computed values of N and measured values of P, T and H were subjected to statistical analysis to obtain their hourly, daily and monthly averages and explore their relationships.

Results

Results of the analyses show that the weather parameters, as well as the surface refractivity derived from them, exhibit clear diurnal and seasonal trends. The results are presented in form of graphs of hourly, daily and monthly averages as shown below.

Diurnal Profiles

As can be seen from Fig. 2a, the profiles of surface temperature and relative humidity are out-of-phase. Hourly mean temperature peaks at 33 °C around 3-4 pm local time and humidity has minimum value of 47% at about the same time; also minimum temperature of 24°C occurs around 7am local time when maximum relative humidity peaks at 66%. Fig. 2b shows that surface refractivity also has a clear diurnal trend which slightly lags the humidity profile.

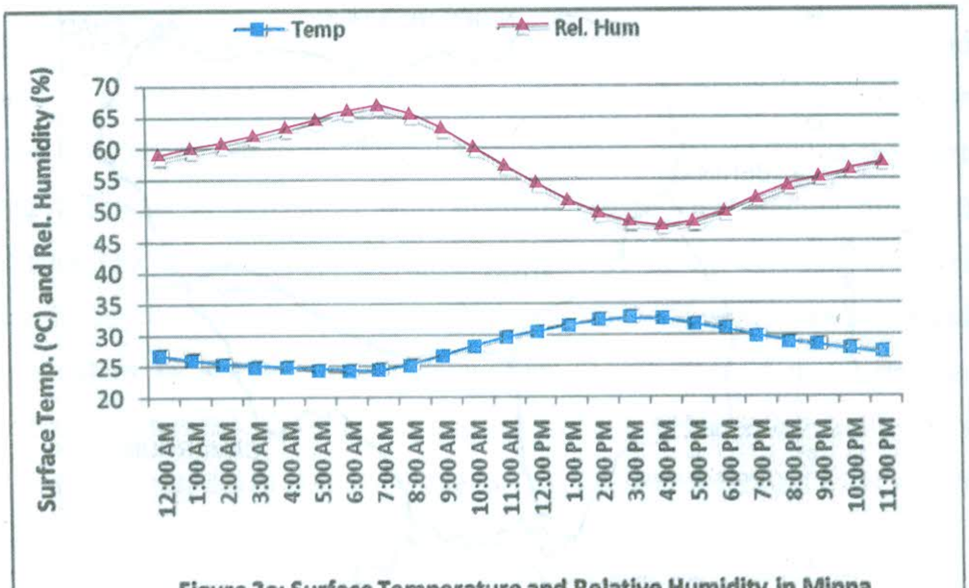

Figure 2a: Surface Temperature and Relative Humidity in Minna

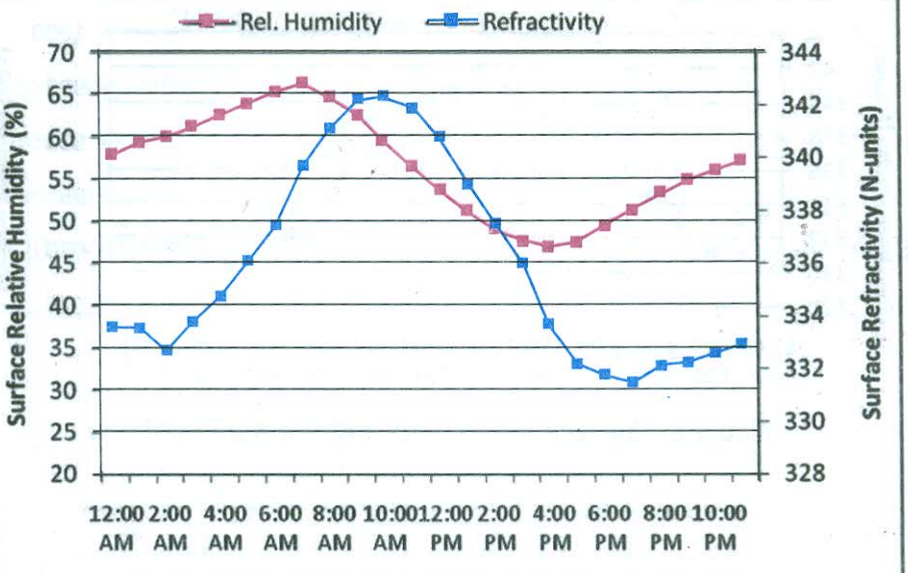

Figure 2b: Surface Refractivity and Rel. Humidity in Minna

Thus, the humidity peak (66%) around 7am is followed by refractivity peak (342 N-units) around 10am local time; while the humidity minimum (47%) around 4-5 pm is followed by refractivity minimum of 331 N-units around 7 pm local time i.e. a time lag of 2-3 hours. Also the diurnal profile of surface refractivity closely follows that of surface pressure, as can be seen from Fig. 2c. The pressure profile peaks at 995 hPa around 9-11am when the N profile peak occurs; also the minimum values of 980 hPa at 2 am and 979 hPa at 7 pm correspond to the occurrence of the N minimum points of 333 and 331 respectively. Further statistical analyses show that the hourly averages of surface pressure and surface refractivity are well correlated with a correlation coefficient of 0.94; and that hourly surface refractivity N values can be reasonably predicted by diurnal values of surface pressure P with the regression equation **$N = 0.622P - 278.6$** as shown in Fig. 2d where N is N-units and P is in hPa.

Surface refractivity also shows some seasonal tendency as can be seen from Fig. 2e. This figure shows that hourly refractivity values are higher in rainy season (370-364) compared to dry season values (295-288). The dry season values have slightly higher range and higher variability. The annual range is 358-343 and peaks around 9-10 am. The dry season variability trend is more clearly observed in the daily refractivity profiles shown in Fig. 3 below.

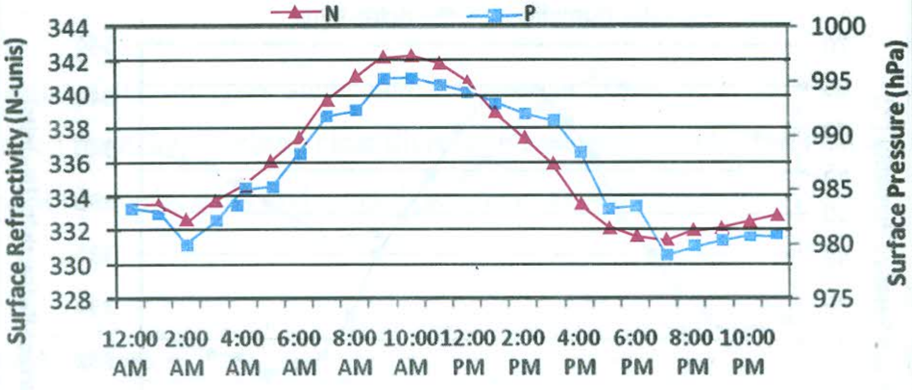

Figure 2c: Surface Refractivity and Pressure in Minna

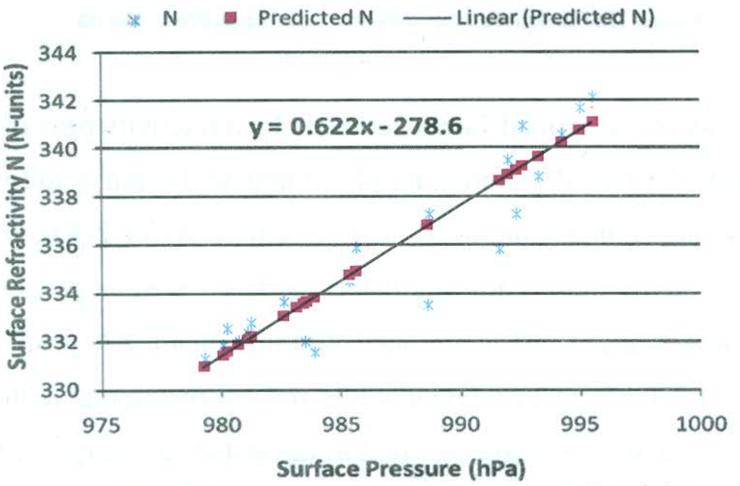

Figure 2d: Linear Regression on Surface Refractivity and Pressure

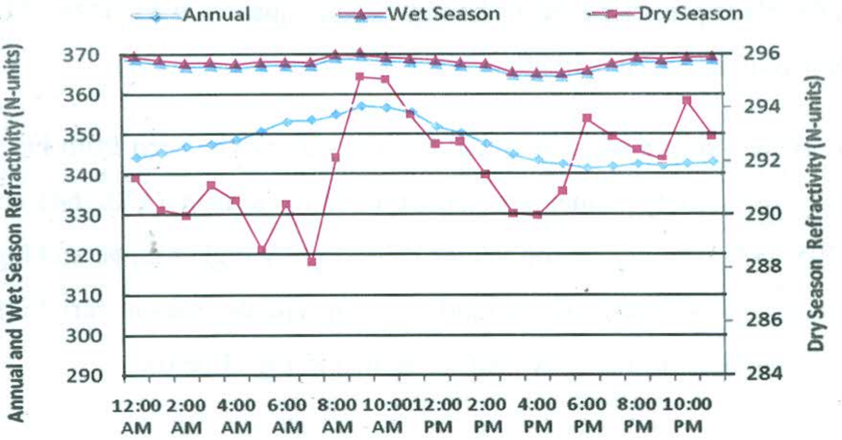

Figure 2e: Diurnal Surface Refractivity in Wet and Dry Seasons in Minna

Daily Refractivity Profiles

Fig. 3 shows that daily refractivity profiles for January (which is a typical dry season month in Nigeria) has greater variability with a range of 63 (i.e. 279 - 342) compared to the values in July (a typical wet season month in Nigeria) with a range of 25 (i.e. 351 - 376) in the two years under consideration (2008-2009). This trend is more strongly revealed by the seasonal profiles.

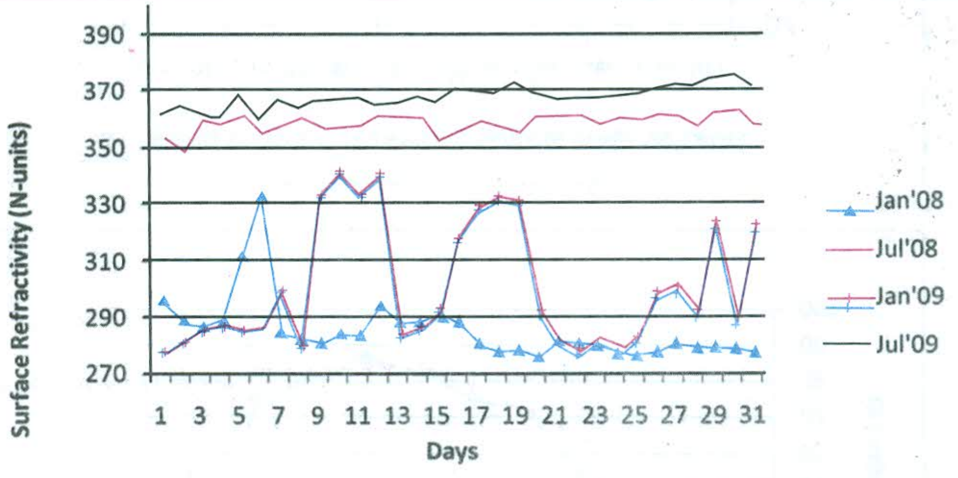

Figure 3:Typical Mean Daily Surface Refractivity in Minna

Seasonal Profiles

The mean monthly profiles of surface refractivity and relative humidity in the two years (2008 and 2009) also reveal a striking similarity as seen in Fig. 4a and 4b, although the values are slightly higher in the year 2009. The correlation coefficient is 0.98 while the regression equation for predicting mean monthly refractivity N from mean monthly relative humidity H is

$N = 1.281H + 262.8$ as shown in Fig. 4c. Peak values occur in Wet Season (May-October) while minimum values occur in Dec-Feb.

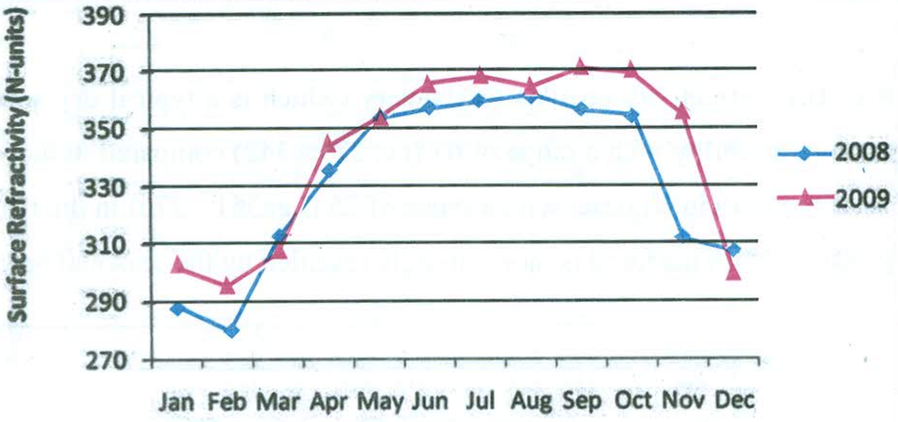

Figure 4a: Mean Monthly Surface Refractivity in Minna

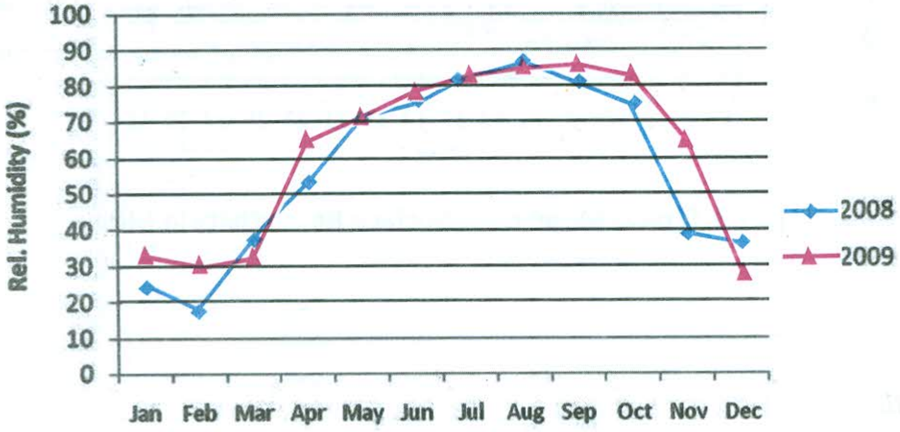

Figure 4b:Mean Monthly Rel. Humidity in Minna

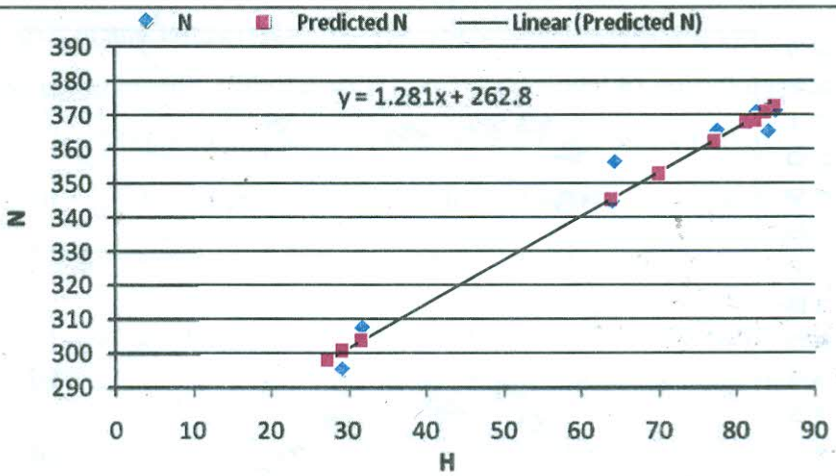

Figure 4c:Linear Regression on Mean Monthly Surface Refractivity and Rel. Humidity (%)

Diurnal and Monthly Surface Temperatures

Values of the hourly surface temperatures were obtained for each month and contoured as shown in Fig. 5 below, which further reveals interesting diurnal and seasonal trends. Maximum monthly average surface temperatures (28-35 ^{O}C) occur in March-April from about 10 am local time through the night to about 4 am, and in November-December from about 10 am local time till around midnight. Thus, night time temperatures are equally high in March-April and the hottest period is between 12 noon and 8 pm. However, whereas high humidity values in April (see Fig. 4b) combine with high temperatures (> 28 ^{O}C) to make the month unbearably hot in Minna, occasional spells of receding Harmattan as well as low humidity levels help to cushion the effects of hot temperatures in March, making the month in Minna much more amenable compared to April. Fig. 5 also shows that minimum temperatures (< 28°C) occur in the month of August, which is generally applicable to most Nigerian stations (Ojo, 1977; Oyedum, 1977)

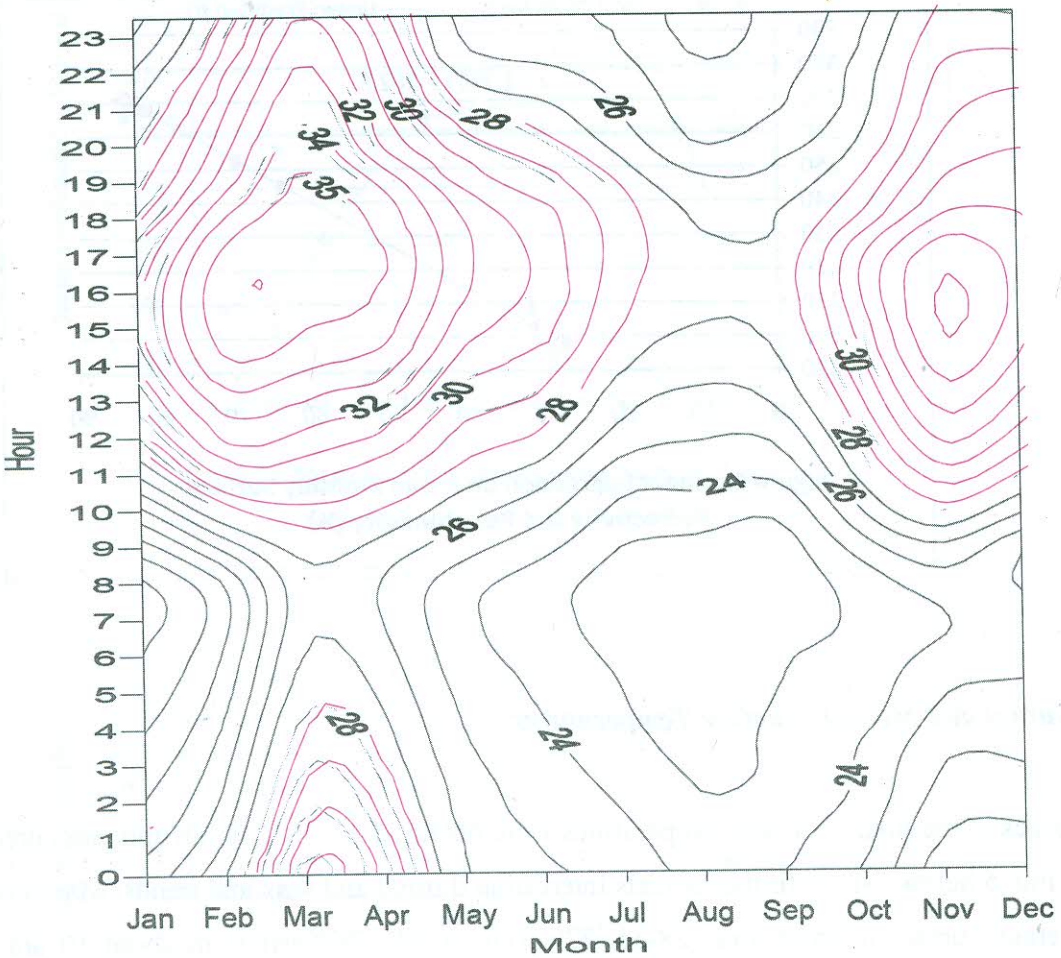

Figure 5: Mean Diurnal and Monthly Temperatures in Minna

Discussion and Conclusion

Analysis of weather parameters monitored in Minna between 2008 and 2009 shows that surface radio refractivity and related meteorological parameters of pressure, temperature and humidity have clear diurnal and seasonal tendencies. The out-of-phase relationship between temperature and humidity results from the fact at surface level moisture concentration is higher at lower temperatures at night and early morning hours, but after dawn temperature rises, increased insolation and water vapour molecules near the surface expand and rise, thus decreasing the surface humidity and consequently surface refractivity, with humidity variations slightly leading refractivity changes. High correlation between diurnal surface refractivity and pressure may be attributed to the fact that at any temperature N_{dry} [see equations (5) and (6)] contributes over 66% to value of N in Nigeria (Adeyemi, 2006); also N_{dry} is proportional to pressure (which as high as 995 hPa at surface level in Minna) while N_{wet} is proportional to humidity and contributes more to variability of N (Hall, 1979). Observed diurnal and seasonal N variability would cause corresponding field strength variations in Minna especially at VHF band.

While diurnal trends depend more on local conditions, the observed seasonality largely manifest the climatic conditions resulting from the North-South migration of the Inter tropical Discontinuity (ITD) across West Africa. The surface position of this low pressure zone represents the meteorological boundary between the rainy season on its southern side of the boundary and the dry season on the northern side. The southern side is characterized by warm southwesterly winds which bring moisture from the Atlantic to the hinterland; while the northern side is characterized by cold and dry north easterlies which may sometimes be accompanied by varying concentrations of dust haze from the Sahara, which worsen the moisture level and increase the variability in dry season due to adsorption by the particulate matter (Adeyemi, 2006).

At such high tropical temperatures prevalent in Minna, N varies considerably with changes in H. The ITD begins its northward movement around January at about latitude 4^{O}N following the 'over-head sun' and reaches its north-most position around latitude 20^{O}N in August (Ayoade, 1983). By July the whole country is saturated with moisture and experiencing rainy season; thus, surface humidity and refractivity values become less variable (Fig. 3). By October the ITD begins the southward movement and increasingly parts of the country (from north to south) experience dry season. The temperature and pressure variations are related to mesoscale and local conditions such as topography, surface albedo, wind systems, etc which are outside the focus of this study. However, the observed predictability of diurnal surface refractivity based on pressure, or seasonal refractivity based on humidity, are interesting results that still need to be fine-tuned based on long-term data acquisition and analysis.

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References

Adebanjo, T.I., 1977. A semi-empirical radio refractive index variation over Nigeria. Bull. *Nig. Inst. Phys.* Vol.2, No.2, pp.69-78.

Adedeji, A.T. and Ajewole, M.O., 2008. Vertical profile of radio refractivity gradient in Akure, South-West Nigeria. *Progress In Electromagnetics Research* C, vol. 4, pp.157-168.

Adeyemi, B., 2006. Surface water vapour density and tropospheric radio refractivity linkage over three stations in Nigeria. *Journal of Atmospheric and Solar-Terrestrial Physics*, 68, pp.1105-1115.

Bean, B.R. and Cahoon, B.A., 1961. Correlation of monthly median transmission loss and refractive index profile characteristics. *J. Res. N.B.S. 65 D,* No.1, pp.67-74.

Bean, B.R. and Thayer, G.D., 1963.Comparison of observed atmospheric radio refraction effects with values predicted through the use of surface weather observations. *J. Res. Natl. Bur. Std.*, D67, No. 3, pp. 273-285.

Bean, B.R., Cahoon, C.A., Samson, C.A. and Thayer, G.D., 1966. *A world atlas of radio refractivity*. Monograph No. 1, Environmental Sciences Services Administration, U.S. Government Printing Office, Washington D.C.

Bean, B.R. and Dutton, E.J., 1968. *Radio meteorology*. Dover Edition, New York, USA. pp. 1-20.

Hall, M.P.M., 1979. Effects of the troposphere on radio communications. London and New York: IEEE Peter Peregrinus Ltd pp.14-46.

ITU-R, 2003. The Radio Refractive Index: Its Formula and Refractivity Data, 453-459.

Kolawole, L.B., 1980. Climatological variations of surface radio refractivity in Nigeria. *Bull. Nig. Inst. Phys*. Vol. 4, 1980, pp.97-117.

Lane, J.A. and Bean, B.R., 1963.A radio meteorological study, Part I: Existing Radio meteorological parameters; Part II: An analysis of V.H.F. field strength variations and refractive index profiles; Part III: A new turbulence parameter. *J. Res. Natl. Bur. Std*., D67, pp.589-604.

Flavell, R.G. and Lane, J.A., 1962.. The application of potential refractive index in tropospheric wave propagation. *J. Atmos. Terr. Phys*. 24, pp.47-56.

Misme, P. 1960. Models of the Atmospheric Radio Refractive Index. *Proc. IRE*, 48, No. 8, pp.1499-1501.

Ojo, O. 1977. *The Climates of West Africa*. Ibadan, Nigeria: Heinemann Educational Books Ltd, pp.13-29

Owolabi, I.E. and Williams, V.A., 1970. Surface radio refractivity patterns in Nigeria and the Southern Cameroons. *J.West Afr. Sc. Assoc*. 15, No.1, pp.3-17.

Owonubi, J.J., 1982. The tropospheric radio refractivity over Africa. M.Sc. Thesis (Unpublished), Dept. of Physics, University of Ife, Ile-Ife, Nigeria.

Oyedum, O.D., 1977. Atmospheric temperature structure over Oshodi-Lagos. B.Sc. Thesis (Unpublished), Dept. of Physics, University of Nigeria, Nsukka, Nigeria.

Oyedum, O.D. and Gambo, G.K., 1994. Surface radio refractivity in Northern Nigeria. *Nig. J. Phys*., Vol. 6, pp. 36-41.

Oyedum, O.D., 2005. Seasonal variability of radio field strength and radio horizon in Nigeria. *Book of Readings, 1st Annual S.S.S.E. Conf. F.U.T., Minna,* Vol. 1, pp.184-195

Oyedum, O.D., Igwe, K. C., Eichie, J. O. and Moses, A.S., 2009. Preliminary results of surface refractivity in Minna, Niger State, Nigeria. Proceedings of Annual Conference of Nigerian Union of Radio Science. In press.

Saxton, J.A., 1963. Proceedings Commission II, Radio and Troposphere, XIVth General Assembly. URSI, Tokyo, pp. 117-126.

Smith, E.K. and Weintraub,S.,1953. The constants in the equation for atmospheric refractive index at radio frequencies. *Proc. Inst. Radio Eng.*, 41, pp.1035-1037.