EFFECTS OF VARIATION OF SOME WEATHER PARAMETERS ON SURFACE REFRACTIVITY

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Abstract

The structure of radio refractive index in the troposphere is needed for the design of efficient radio communication systems. In this study, measurement of atmospheric pressure, temperature and relative humidity at ground level was made at the Tropospheric Data Acquisition Network (TRODAN) of Physics Department, Federal University of Technology Minna, Niger State. The data analysed were taken at intervals of 5 minutes daily. The results obtained show that the dry season months had lower values of refractivity ranging from 283 N-units in January to 312 N-units in March while the wet season months recorded higher refractivity values ranging from 356 N-units in May to 358 N-units in September. From these measurements, the sensitivity of surface radio refractivity to weather parameters was analyzed and the regression analysis carried out shows that mean values of pressure fairly correlated with surface refractivity while mean values of humidity had high correlation with surface refractivity.

Keywords: Humidity, Pressure, Surface Refractivity and Temperature

1. Introduction

The knowledge of the ratio of the velocity of propagation of a radio wave in free space to the velocity of the wave in a medium called the atmospheric radio refractive index is very important in the design of radio communication links (Freeman, 2007). Weather conditions have significant effects on radio wave propagation in the atmosphere because variations of the meteorological parameters of pressure, temperature and water vapour pressure result to variations in the radio refractive index which in turn is responsible for the refraction and scattering of electromagnetic waves propagating through the troposphere (Hall and Barclay, 1991). Thus, good knowledge of surface refractivity 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, Nigeria which has good agricultural and tourism potentials (Oyedum *et al.,* 2011). The radio refractive index of the atmosphere does not only affect the curvature of the radio wave but also gives insight into the fading phenomenal (Freeman, 2007).

In the design of radio communication systems operating in the very high frequency (VHF) bands and above, the radio scientist normally subjects long term data relating to atmospheric refractive index and its properties to statistical analysis in order to be able to predict these parameters (Aro and Willoughby, 1992). In this study, surface refractivity values were computed from values of temperature T, air pressure P, and relative humidity H measured in Minna, Central Nigeria. These were analysed statistically so as to explore their diurnal and seasonal variation as well as their inter-relationships with surface refractivity.

Earlier researchers in this field have observed surface refractivity to correlate well with refractivity gradient in the first one kilometer above the earth surface. Bean and Thayer (1959) first investigated the correlation existing between monthly mean of surface refractivity, N_s and monthly mean of refractivity decrease in the first kilometer above ground, ΔN and obtained the relation $-\Delta N = A \exp(BN_s)$, where A and B are constants that are characteristic of each region. Adebanjo (1977) determined an empirical relation of the form $\Delta N = -25 \exp(0.0022\, N_s)$ to indicate the average change in refractivity between surface, N_s and refractivity in the first kilometer above ground, ΔN over Nigeria. Kolawole (1983) deduced the empirical relation of the form $\Delta N = -2.3 \exp(0.00863\, N_s)$ based on 1130 sets of data from 47 African radiosonde stations. Aro and Willoughby (1992) obtained a correlation coefficient of 0.76 between mean values of surface refractivity and mean values of refractivity decrease in the first kilometer above ground for four meteorological stations in the West African sub-region.

Some others have observed that good correlation exists between surface refractivity, N_s and radio field strength. Lane and Bean (1963) obtained a correlation coefficient of 0.70 between surface refractivity and VHF field strength and a correlation coefficient of 0.71 between refractivity gradient in the first one kilometer above the earth surface, ΔN and VHF field strength. Oyedum and Gambo (1994) obtained a correlation coefficient of 0.73 between surface refractivity, N_s and transhorizon VHF field strength values in Northern Nigeria; while others have established that correlation exists between some weather parameters and signal strength. Bullington *et al* (1955) observed that hourly median signal levels were low during snowstorms but enhanced during foggy periods by 5 to 10 dB on a link in Newfoundland, Canada. This change in the signal level was attributed to the fact that various weather situations are associated with characteristic distributions of radio refractivity. Aboaba and Jegede (2001) examined the correlation of VHF radio signals and meteorological conditions of over-the-horizon paths in the South-western part of Nigeria, and observed that correlation coefficient between signal level and water vapour pressure was high during super-refractive conditions.

Also, other researchers have observed that surface refractivity correlated with some weather parameters. Oyedum *et al* (2011) obtained correlation coefficient of 0.98 between mean monthly surface refractivity and mean monthly relative humidity while a regression equation of $N_s = 1.281H + 262.8$ for predicting mean monthly surface refractivity, N_s from mean monthly relative humidity, H was also obtained in Minna, Nigeria. In addition, a correlation coefficient of 0.94 was obtained between hourly averages of surface refractivity and surface pressure and then deduced that hourly surface refractivity N_s values can be reasonably predicted by diurnal values of surface pressure, P with the regression equation $N = 0.622P - 278.6$. Igwe *et al* (2011) obtained a correlation coefficient of 0.97 between mean monthly surface refractivity, N_s and mean monthly relative humidity, H while a regression equation of $N = 0.881H + 279$ for predicting mean monthly surface refractivity, N_s from mean monthly relative humidity, H was also obtained in Ilorin, Nigeria.

As a result of the diurnal and seasonal variation of these atmospheric parameters and in the light of climate change, the results obtained from this research work will guide the radio scientist or engineer interested in designing radio links in this region.

2. Data Acquisition

The data used for this research work were acquired from the Tropospheric Data Acquisition Network (TRODAN) situated at the Federal University of Technology, Bosso Campus, Minna, Niger State. The measurement was made daily for one year (January-December 2011) at 5 minutes intervals. The instrument used for the measurement of the required weather parameters is the Campbell-CR1000 data logger (Fig. 1). The CR1000 data logger comes with a multi-port module which enables it to interface with other electronic sensors. Low power consumption allows this datalogger to operate for extended time periods on a battery recharged with a solar panel thereby eliminating the need for AC (alternating current). The CR1000 module controls external devices and stores data and programs in on-board, non-volatile storage. It simultaneously provides measurement and communication functions.

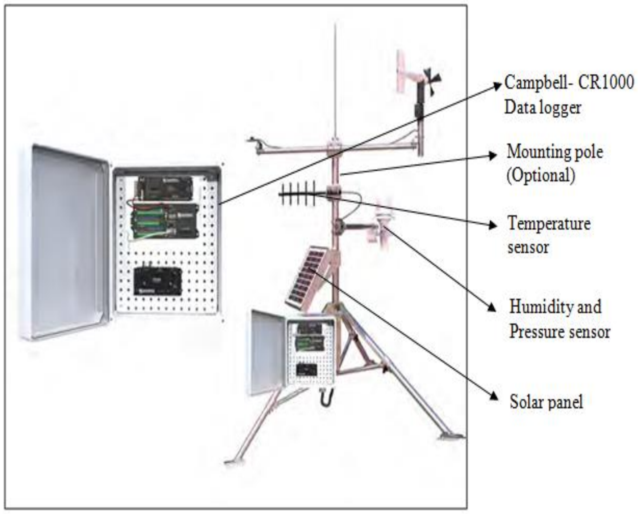

Fig. 1: The Campbell- CR1000 data logger

3. Methodology

The radio refractivity N is given by the formula (ITU-R, 2003):

$$N = (n-1) \text{ X } 10^6 = 77.6/T\,[P + (4810e/T)] \quad (1)$$

where n is the atmospheric refractive index, P is the atmospheric pressure in hPa, e is the water vapour pressure in hPa and T is the absolute temperature in K. Equation 1 may be expanded and rewritten as

$$N = [77.6P/T] + [3.73 \text{ X } 10^5 e/T^2] \quad (2)$$

the first term is called the dry term, that is,

$$N_{dry} = 77.6P/T \quad (3)$$

while the second term is called the wet term:

$$N_{wet} = 3.73 \text{ X } 10^5 e/T^2 \quad (4)$$

the vapour pressure, e is estimated from (Hall, 1979):

$$e = (R.H \text{ X } e_s)/100 \quad (5)$$

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

e_s is calculated from (Hall, 1979):

$$e_s = 6.11\,exp\,[(19.7t)/(t+273)] \quad (6)$$

t is the temperature in °C.

4. Results and Discussion

The measurements of the three atmospheric parameters: temperature, pressure and relative humidity were done in both seasons (the dry and wet seasons) occurring in Minna.

4.1 Diurnal variation of surface refractivity

The mean hourly variation of surface refractivity for a typical dry season month (January) is shown in Fig. 2a. Peak value of 286 N-units occurs in the midnight after which it begins to decrease until a minimum value of 275 N-units is reached by 4.00 pm local time. Refractivity values begin to increase again towards the evening and midnight hours. The mid-day and afternoon minimum could be attributed to the simultaneous effects of high temperatures and low humidity which reduces the moisture content of the atmosphere during this period while the midnight and early morning peak is as a result of increased water vapour content at night. Comparing this result with that of a typical wet season month, for example, the month of May (Fig. 2b), it is observed that refractivity values were higher but less variable than the dry season months.

Midnight and early morning values ranged between 358 N-units to 361 N-units while afternoon values ranged between 349 N-units to 353 N-units.

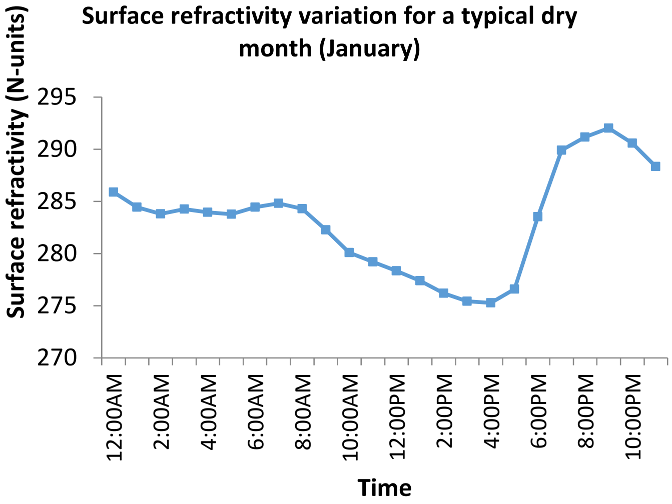

Fig. 2a: Diurnal variation of surface refractivity for a typical dry month

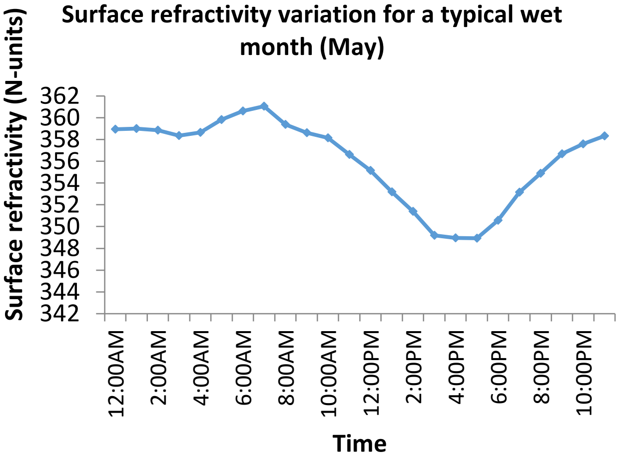

Fig. 2b: Diurnal variation of surface refractivity for a typical wet month

On the average, dry season refractivity values ranged between 277 N-units to about 281 N-units while the wet season values ranged between 326 N-units to about 328 N-units.

4.2 Variation of atmospheric parameters with surface refractivity

Variation of average diurnal profile of relative humidity and surface temperature is shown in Fig. 3a. Both parameters are out-of-phase as observed from the graph. Between midnight to around 7.00 am local time, mean hourly temperature has minimum values of about 24 ^{0}C and 25 ^{0}C when relative humidity peaks between 61% and 65%. Also, when temperature peaks at 3.00 pm local time with a value of 33 ^{0}C, humidity has a minimum value of 37% - 39% at the same time. This has clearly shown that when air temperature is high, the atmosphere is less humid and vice versa. The variation of surface refractivity with temperature is shown in Fig. 3b. The graph shows a similar trend with Fig. 3a confirming that refractivity is inversely proportional to temperature as given in equation 2 and further proving that refractivity is less sensitive to temperature. This out-of-phase relationship results from the fact that at surface level, moisture concentration is higher at lower temperatures during the night and early morning hours, but temperature rises during the day thereby expanding water vapour molecules near the surface and thus decreasing surface humidity and consequently surface refractivity.

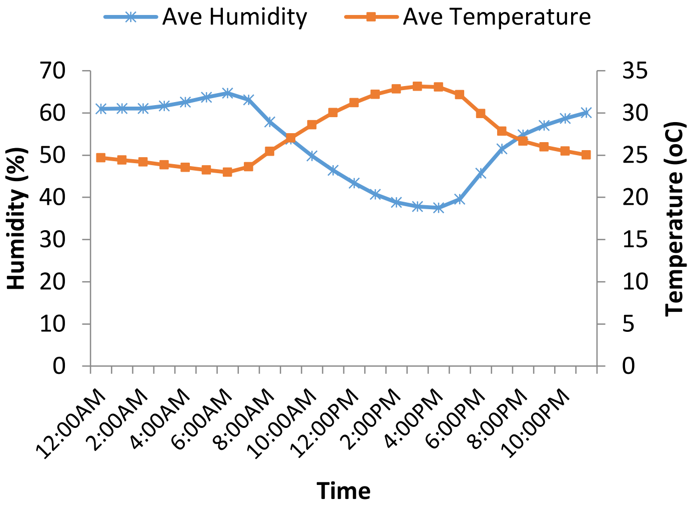

Fig. 3a: Humidity and temperature variation

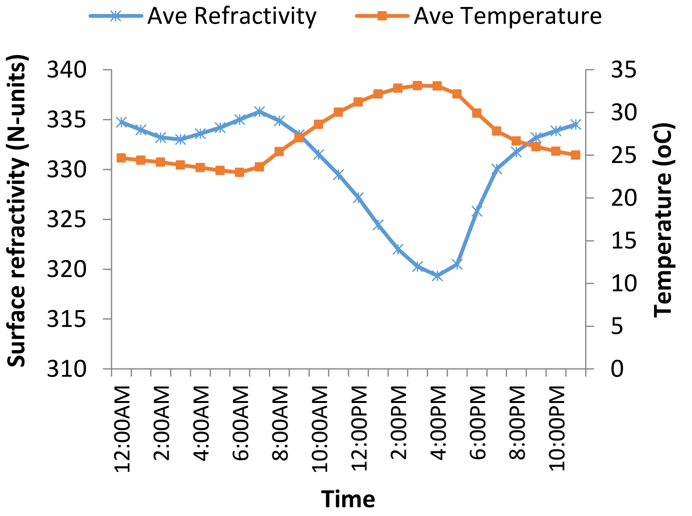

Fig. 3b: Surface refractivity and temperature variation

The plot for surface refractivity and relative humidity is shown in Fig. 3c. From the graph, it is obvious that surface refractivity has a diurnal trend with humidity and they are both in-phase with each other. As a result, humidity peak of 65% by 6.00 am local time is immediately followed by refractivity peak of 335 N-units at exactly the same time while humidity minimum of 37% by 4.00 pm local time is followed by refractivity minimum of 319 N-units at the same time.

The average diurnal profile of surface refractivity and surface pressure was also examined. From Fig. 3d, it is observed that they are both out-of-phase during the early morning hours but closely follow each other with a little time lag from 8.00 am till midnight hour. Pressure has 2 minima and two maxima while refractivity has one minimum and two maxima. The first pressure minimum occurred around 2 am - 4 am local time with a value of 978 hPa while surface refractivity peak of 333 N-units also occurred around the same time. By 8.00 am local time, a refractivity peak of 335 N-units occurs which is followed by a pressure peak of 981 hPa by 9.00 am thereby having a time lag of 1 hour, while a refractivity minimum of 319 N-units around 4 pm local time is followed by a pressure minimum of 976 hPa at the same time. The second pressure maxima occurred by 11.00 pm local time with a peak value of 980 hPa which is also followed by a refractivity peak value of 335 N-units at the same time.

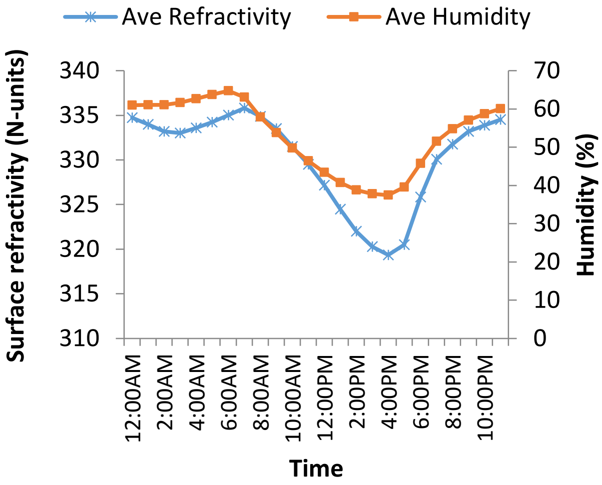

Fig. 3c: Surface refractivity and humidity variation

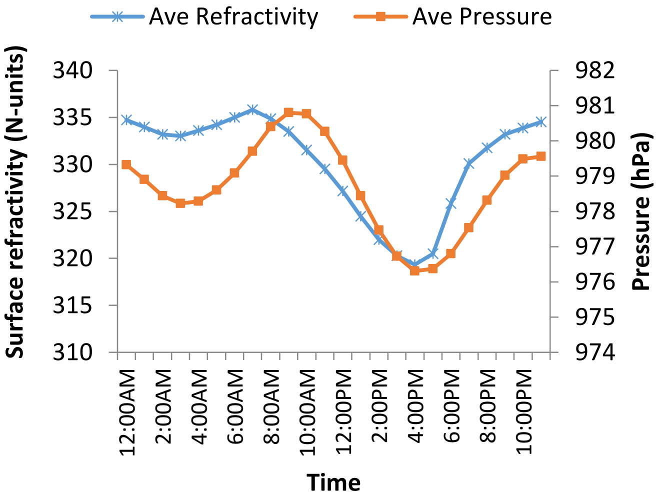

Fig. 3d: Surface refractivity and pressure variation

Further analyses reveal that mean values of humidity and surface refractivity are well correlated with a correlation coefficient of 0.90 (Fig. 3e), while mean values of pressure and surface refractivity fairly correlated with a correlation coefficient of 0.52 (Fig. 3f). Also, mean surface refractivity, N_s can be predicted by mean values of humidity using the equation N = 0.534H + 301.9 while mean surface refractivity, N_s can likewise be predicted by mean values of pressure from equation N = 2.923P - 2531 where N is surface refractivity in N-units, H is the humidity in % and P is pressure in hPa.

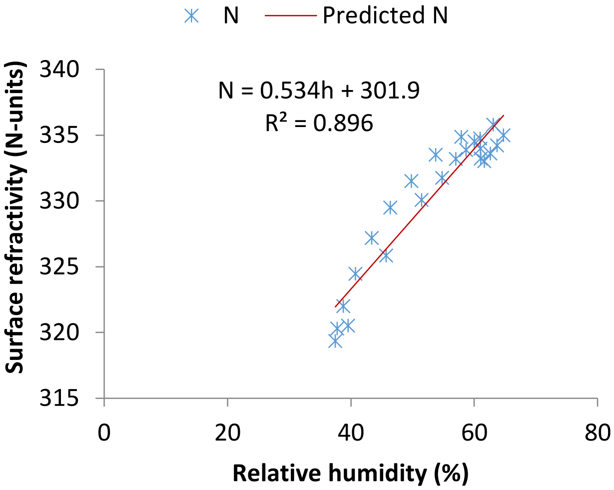

Fig. 3e: Linear regression on mean surface refractivity and relative humidity

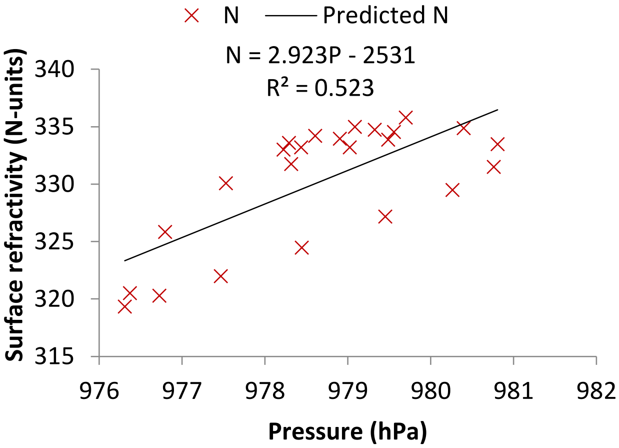

Fig. 3f: Linear regression on mean surface refractivity and pressure

The high correlation observed between mean surface refractivity and humidity is because the wet term of refractivity is proportional to humidity as shown in equation 4 and it contributes more to the variability of refractivity indicating that water vapour pressure is more variable than total atmospheric pressure. The correlation that existed between diurnal surface refractivity and pressure could be attributed to the fact that at any temperature and at any time of the season, the dry term of refractivity in equation 3 contributes about 70% to the total value of refractivity since it is proportional to pressure (which is as high as 982 hPa at surface level in Minna).

4.3 Seasonal variation of surface refractivity

The seasonal variation of surface refractivity is shown in Fig. 4. Minimum values occur in the dry season (November to March) while peak values occur in the wet season (April to October). Refractivity values vary between 328 N-units in April to 363 N-units in July during the wet season. When the dry season sets in by November, N_s values fall sharply from 330 N-units in November to 294 N-units in December and reaching lowest value of 286 N-units in January. This is followed by a steeper rise of 321 N-units in February to 319 N-units in March, thereby showing that refractivity is more variable in the dry season. August is not shown because there was no data recorded for the month. The low refractivity values recorded in the dry season is as a result of high temperatures and consequent low humidity of the atmosphere prevalent during this period while the higher values recorded during the wet season is as a result of the high humidity brought about by rainfall during this period.

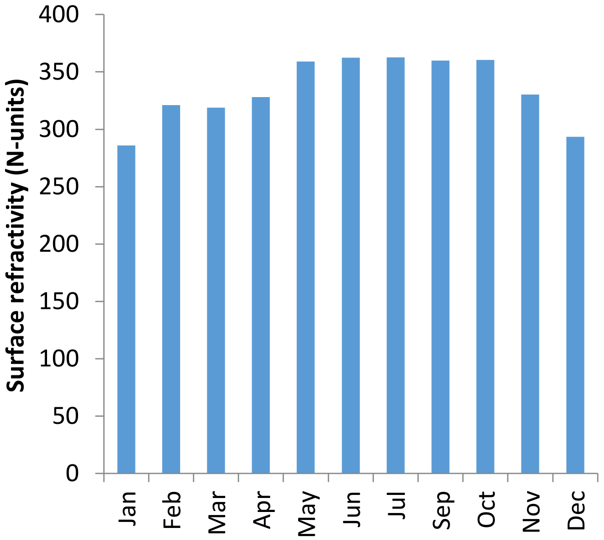

Fig. 4: Seasonal variation of surface refractivity

5. Conclusion

The analysis of surface radio refractivity and related weather parameters in Minna, Nigeria shows diurnal and seasonal trends. The results obtained reveal that surface radio refractivity is more variable in the dry season than the wet season and that refractivity values are lower in the dry season than the wet season. Also, a high correlation has been observed between mean surface refractivity and humidity and this has been adduced to the fact that the wet term of refractivity is proportional to humidity, thus contributing more to the variability of refractivity. Consequently, this shows that water vapour pressure is more variable than total atmospheric pressure.

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