CHARACTERISTICS OF TROPOSPHERIC SCINTILATION FOR SATELLITE APPLICATIONS IN JOS

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ABSTRACT

This paper presents the results of the hourly variation of refractivity based on measurement of temperature, atmospheric pressure and relative humidity in Gold and Base, Jos (09°58'N, 008°57'E, 1192m), (near Air Force Military School-AFMS*)*, Nigeria. Twelve months meteorological data were measured with DAVIS Vantage Vue weather station; and were used to compute the surface radio refractivity and the scintillation fade depth following the ITU-R P.834 prediction model. Correlation values showed that the average hourly variations of refractivity in the dry season remained low, mainly as a result of the low values of the wet component – humidity; while the average daily values of surface radio refractivity in the rainy season varied mainly as a result of both variations in the dry (pressure) and wet (humidity) components of surface radio refractivity. Diurnal curves in the dry season showed minimum values in the mid-morning to late afternoons (10:00 – 16:00), and maximum values from evening to early morning hours (18:00 – 08:00); while the rainy season has a fairly constant average refractivity index of about 345 units. Seasonal values of surface radio refractivity varied between 276 and 330 units during dry season; while the values varied between.348 and 338 units during rainy season Also, scintillation fade depth ranged from 0.95dB to 2.05dB during dry season; and from 1.788dB to 2.20dB in the wet season. For future research, it is suggested that different single-parameter models could be developed for dry season and during the rainy season. While an inverse temperature-dependent model is required for dry season, a pressure-dependent model would suffice for rainy season.

Keywords: Meteorological parameters, Wet-term Refractivity, Scintillation fade depth, ITU-R

1.0 INTRODUCTION

Advanced communications systems such as satellites, radars, GSM have ensured seamless information sharing that has led to technological advances in military warfare, agricultural development and practices, and health care delivery systems, and so on. However these atmospheric have adverse effects on the satellite signals propagation, which necessitates constant research and redesign of communication systems. When the signal encounters turbulence in the atmosphere, there are rapid changes in the refractive index along the signal path that elicit signal level fluctuations [1, 2] However, considerations about tropospheric scintillation become important for low-frequency margin systems when designing link budgets that operate at high frequency and low elevation angles [2].

Tropospheric fluctuations gives rise to time-varying changes of the refractive index, creating random amplitudes, phases, and angles of arrival in radio signals, called scintillation. Scintillations occur mainly due to the variation in the refractive index of the medium of propagation. Scintillation intensity is often described by the fluctuation or standard deviation of its probability distribution. Within the standard atmosphere, the actual mean square amplitude of the scintillation would be increased with an increase in relative humidity. Scintillation occurs continuously, irrespective of whether the sky is clear or rainy [3, 4]. During the rainy months there is more fade with rain-filled clouds than dry clouds. When the temperature is high with low humidity, the signal-level fluctuations due to tropospheric scintillation are less. [5] and [6] showed that scintillation depends on meteorological parameters, especially temperature, humidity, and the refractivity of wet periods. In the dry season, the scintillation is stronger than in the wet season for both clear wind and rain conditions. The intensity of the tropospheric scintillation is very high at low elevation angles and antenna size [7].

This paper sets to compute the surface radio refractivity and the scintillation fade depth following ITU-R prediction model in [8]. The impact of each meteorological parameter was also investigated. The results could serve as empirical reference for planning tropospheric wave propagation, especially in determining the coverage and quality of service of communication signals at the location.

2.0 METHODOLOGY

DAVIS Vantage Vue weather station installed at the ground surface in Gold and Base, Jos (09^o58'N, 008^o57'E, 1192m), (near Air Force Military School-AFMS), Nigeria was used to measure the surface pressure, temperature, and relative humidity from October 2013 to September 2014. The one minute data for each hour of the day was averaged to give a data point for each hour of the day. Then the average for each hour was taken over the month to give a data point for the month. The data were used to compute the surface radio refractivity and the scintillation fade depth following the steps recommended by ITU-R prediction model in [8]. The steps for calculation of monthly and long-term statistics of amplitude scintillations at elevation angles greater than 5^o are given below [8]:

Step 1: For the value of temperature t, calculate the saturation water vapour pressure, e_s (hPa):

$$e_s = a\exp(\frac{bt}{(t+c)}) \tag{1}$$

Where, $= 6.112,\ b = 17.50,\ \ c = 240.97\ ,\ t = celcius\ temperature$

Step 2: Compute the wet term of the radio refractivity, N_{wet}, corresponding to e_s, t and humidity, H:

$$N_{wet} = 3.732 \times 10^5 \left(\frac{e}{T^2}\right) \tag{2}$$

Where, $e = \left(\frac{H \times e_s}{100}\right)$ and T is Kelvin Temperature (3)

Step3: Calculate the standard deviation of the reference signal amplitude:

$$\sigma_{X.REF}\sigma_{X.REF} = 3.6 \times 10^{-3} + 10^{-4} N_{wet} \qquad dB \tag{4}$$

Step 4: Calculate the effective path path length L in metres for height of the turbulent layer, h_L:

$$L = \frac{2h_L}{\sqrt{sin^2\theta + 2.35 \times 10^{-4}} + sin\theta}\ ,\quad h_L = 1000m,\quad (0 \le \theta \le 10) \tag{5}$$

Step 5: Estimate the effective antenna diameter, D_{eff}, from the geometric diameter, D, and the antenna efficiency η:

$$D_{eff} = \sqrt{\eta}D \qquad \text{For the Ku-band set-up, } \eta = 0.5,\quad D = 0.9\ m \tag{6}$$

Step 6: Calculate the antenna averaging factor:

$$g(x) = \sqrt{3.86((x^2+1)^{11/12}.\sin\left[\frac{11}{6} tan^{-1}\frac{1}{x}\right] - 7.08x^{56}} \tag{7}$$

Where, $x = 1.22D_{eff}^2(f/L)$ For the Ku-link set-up, $f = 12.245\ GHz$ (8)

If the argument of the square root is negative (i.e. when $x \ge 7.0$), the predicted scintillation fade depth for any time percentage is zero and the following steps are not required.

Step 7: Calculate the standard deviation of the signal for the application period and propagation path:

$$\sigma = \sigma_{ref}\ f^{7/12}\frac{g(x)}{(sin\theta)^{1.2}} \tag{9}$$

Step 8: Calculate the time percentage factor, $a(p)$, for the time percentage, p, in the range between $0.01\% < p < 50\%$. A time percentage of 0.01 was used for Ku-band link:

$$a(p) = -0.061(log_{10}p)^3 + 0.072(log_{10}p)^2 - 1.71log_{10}p + 3.0 \tag{10}$$

Step 9: Calculate the fade depth, A(p), exceeded for p% of the time:

$$A(p) = a(p).\sigma \qquad dB \qquad 0 \le \theta \le 10 \tag{11}$$

3.0 RESULT AND DISCUSSION

3.1 Seasonal variation of wet-term of Refractivity Index, N_{wet}

The dry season curves in figure 1(a) shows curves for October 2013 to March 2014, where October 2013 had the maximum refractivity of 332; and February 2014 had a minimum of 276 units. For the various months, all the curves follow a similar pattern that mimics the solar activity on the troposphere. In the early hours of the day (00:00 – 08:00) surface refractivity have a fairly constant high value (290 in Feb – 330 in Oct), drops sharply to values between 276 in Feb, and 308 in Oct, remains fairly constant at mid-day (10:00-16:00), after which it rises back to its peak value for the day.

On the contrary, the rainy season curves in figure 1(b), all the curves, except for April 2014, show a fairly constant surface refractivity that varies from between 335 and 348, throughout the day. April 2014 shows a pattern akin to dry season curve which dips from 338 to 308; and may therefore be classified as a dry season month in Jos. The seasonal variations show a maximum and minimum value for dry season, while the rainy season has a constant average refractivity index of about 345 units.

3.2 Seasonal Variation of Temperature, Humidity Pressure and their Impact on N_{wet}

Figures 2 through 4 are presented to determine the impact of various meteorological parameters on the wet term of refractivity index, N, by comparing the various curves. From inspection, in the dry season, the wet term of refractivity (N_{wet}) curves tend to mimic the relative humidity curves, and the inverted form of the temperature curves. In the rainy season N_{wet} curves tend to mimic the pressure curves. This suggests that for the purpose of modelling, during dry season, N_{wet} could be modelled with a simple inverse-temperature-dependent model, or a model proportional to relative humidity. On the other hand, during the rainy season, a pressure – dependent model would suffice. This modelling hypothesis would be subject for further investigations and future research.

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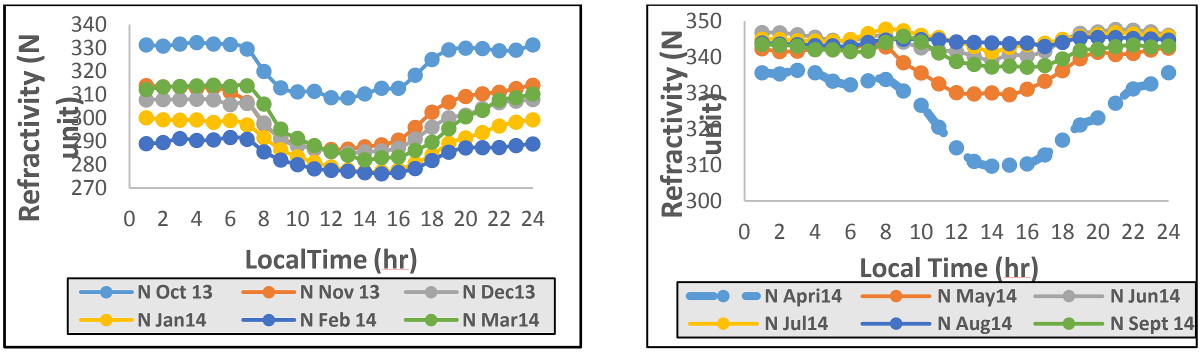

Figure 1: Hourly variation of wet term refractivity in (a) Dry season and (b) Rainy season

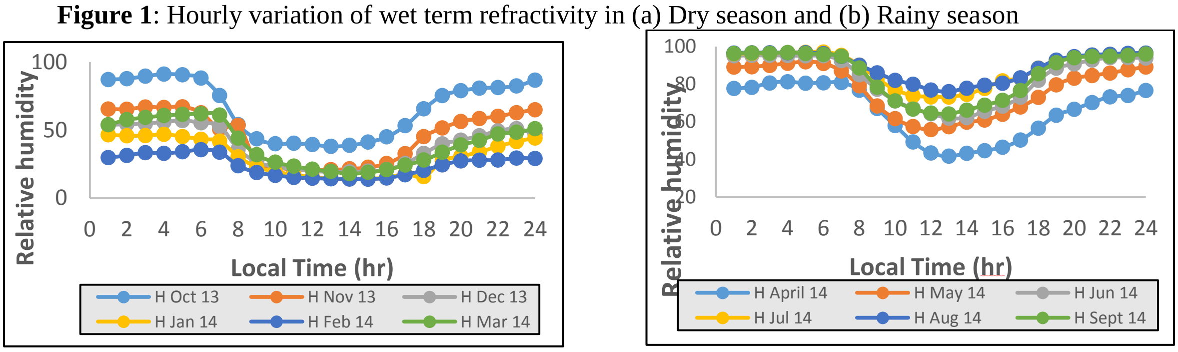

Figure 2: Hourly variation of Relative humidity in (a) Dry season and (b) Rainy season

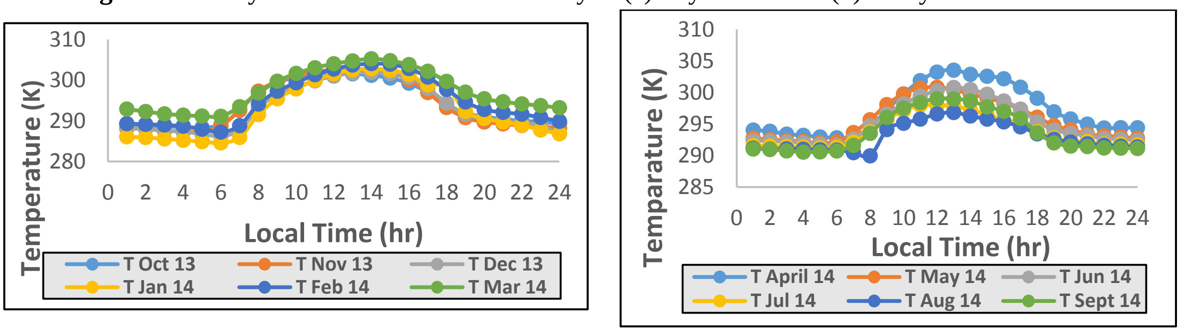

Figure 3: Hourly variation of Temperature in (a) Dry season and (b) Wet season

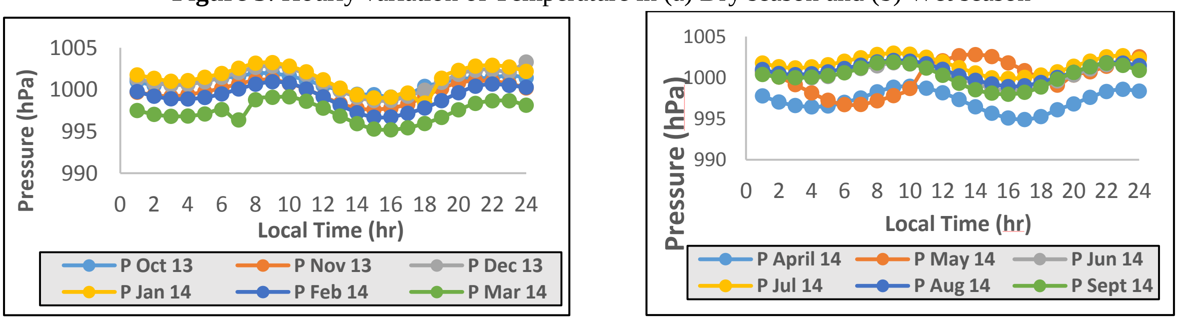

Figure 4: Hourly variation of Pressure in (a) Dry season and (b) Wet season

3.3 Seasonal Variation of Scintillation Fade Depth

Figure 5 (a) shows that the highest scintillation fade depth during dry season was most prominent in the month of October (2.05dB) while the lowest was recorded in January (0.95dB). It is also observed that scintillation is fairly constant in the early hours of the day (00:00 to 07:00) with sharp decline from 07:00 to

10:00; it maintains a fairly constant value during the hours of 10:00 to 15:00; and then rises for the rest of the day. The period of decline is the period hottest period of the day when the atmospheric humidity is lowest.

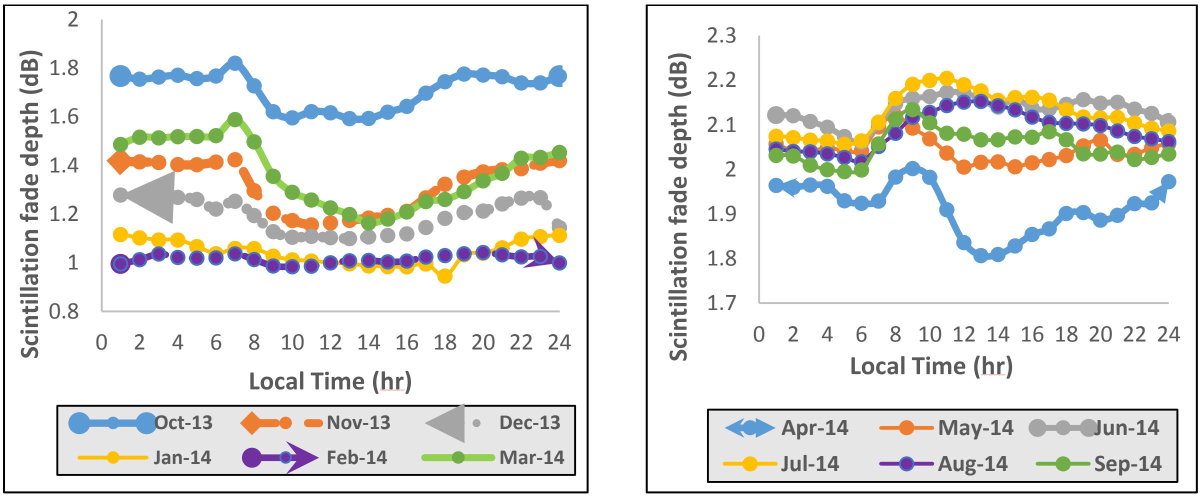

Figure 5: Hourly variation of scintillation fade depth in a) Dry season and b) Wet season

A contrary trend was observed in Figure 9(b) for the wet season, where scintillation fade is fairly constant at the early hours of the day (00:00 to 07:00) with a sharp rise and low decline due to excess humidity. For April and May, they are fairly constant at the early hour of the day with sharp rising and decline, afterward rise. The highest scintillation fade depth during wet season was most prominent in the month of July 2014 (2.20dB) while the lowest was recorded in April 2014 (1.81dB). June, July, August and September

5.0 CONCLUSION AND RECOMMENDATIONS

This research work used meteorological parameters (temperature, pressure and humidity) to compute the wet-term of refractivity for a year (Oct 2013 – Sept 2013). The ITU-R P. 834 (2017) prediction model was used to determine the Scintillation fade depth in the location. The hourly variation of radio refractivity and the scintillation fade depth at the station under study. The major findings of this study are as follows: The average hourly variation of refractivity in the dry season is largely as a result of the variations of the wet component of refractivity while the average variations of refractivity in the rainy season is as a result of both the variations of the wet and dry components of refractivity. For future research, it is suggested that different single-parameter models could be developed for dry season and during the rainy season. While an inverse temperature-dependent model is required for dry season, a pressure-dependent model would suffice for rainy season.

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