International Journal of Engineering and Applied Sciences (IJEAS)
Vol.2, Issue 2(2010)63-68

EMPIRICAL EVALUATION OF WET -TERM OF REFRACTIVITY IN NIGERIA

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Accepted Date: 18 October 2009

Abstract

This paper presents the evaluation of the wet-term of the surface refractivity for twenty three sites in Nigeria carefully selected such that there is wide coverage for the country using ten-year data collected from Nigeria Meteorological Agency. The analysis showed that the southern sites have higher N-wet values compared to the northern sites. 50 % of the time, wet term refractivity is higher than 100 N-units in the southern sites. However, six out of eleven northern sites considered have values less than 50 N-units during the dry season.

Keywords: Refractivity, Wet term, N-wet, Nigeria, Troposphere, Propagation

1. Introduction

Radio signal transmissions at frequencies above 30 MHz are affected by the tropospheric refraction [1]. The tropospheric refraction is due to the fluctuations of weather parameters like temperature, pressure and relative humidity primarily at the lower part of the earth called the troposphere. The troposphere is the lower part of the atmosphere which extends from the earth surface to an altitude of about 10 km at the earth's poles and 17 km at the equator [2]. These fluctuations cause the refractive index of the air in this layer to vary from one point to the other.

Refraction that occurs in the lower atmosphere significantly influences the performance of wireless communication system. Long range electromagnetic wave propagation in near-horizon duration is largely governed by spatial distribution of the refractive index in the atmosphere [3]. Refractivity variation is responsible for various phenomena in the wave propagation such as range and elevation errors in radar acquisition, refraction and fading of electromagnetic waves, ducting and scintillation [4, 5, 6]. Therefore, consideration of the refractive properties of the lower atmosphere is of certain importance when planning and designing terrestrial communication systems mainly because of multi-path fading and interference due to trans-horizon propagation.

The wet term of refractivity contribution in this respect is usually significant. Many models of scintillation, which is the rapid fluctuation of signal amplitude and phase due to small scale variation in refractivity, establish a linear relation between the scintillation variance and the wet-term of refractive index [7]. Examples of such are the ITU-R model, Karasawa model, Otung model, and Orgies model [8, 9, 10, 11] models.

2. Literature Review

The refractive index of the atmosphere is close to unity and the variation is so small, which make it difficult to work with. A more convenient variable to use when modelling the variation of refractive index in the atmosphere is the refractivity, N which is defined as

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

where n is the refractive index of the atmosphere
Refractivity and meteorological parameters such as the atmospheric pressure, temperature and vapour pressure are related by [12]:

$$N = \frac{77.6}{T}\left(P + 4810\frac{\mathbf{l}}{T}\right) \quad = 77.6\frac{P}{T} + \left(3.732\times 10^{5}\frac{\mathbf{l}}{T^{2}}\right) \qquad (2)$$

The refractivity of the atmosphere is divided into two parts; the dry component, N_{dry} and the wet component, N_{wet}. The dry term contributes about 70 % to the total value of the refractivity but the wet term contributes to the major variation [14]. The N_{dry} is proportional to the density of the gas molecules in the atmosphere and changes with their distribution. The N_{dry} component of refractivity, which is fairly stable, can be modelled with an accuracy of about 2 % using surface measurements of pressure, P (hpa) and temperature, T (Kelvin) [13] as

$$N_{dry} = 77.6\frac{P}{T} \qquad (3)$$

While the wet term, which is due to the polar nature of the water molecules, is given by

$$N_{wet} = 3.732\times 10^{5}\frac{\mathbf{l}}{T^{2}} \qquad (4)$$

$\mathbf{l}$ is the water vapour pressure and it is given as

$$\mathbf{l} = \frac{H\mathbf{l}_{s}}{100} \quad \text{(hPa)} \qquad (5)$$

where $\mathbf{l}_{S}$ is the saturation vapour pressure at temperature t (^{o}C) given as

$$\mathbf{l}_{s} = a\exp\left(\frac{bt}{t+c}\right) \qquad (6)$$

and coefficients a, b, and c are the constants given as 6.1121, 17.502 and 240.97 respectively for region with temperature range of -20^{o} to 50^{o}.

3. Method

To avoid possible misleading indications related to year to year variation in weather condition, ten-year data was considered in order to obtain a good climatological average. The measurements were taken on hourly basis. Twenty three states were considered using the centres with constant record of observation. The states are grouped into two parts for proper analysis – the northern sites and the southern sites. The northern sites are Jos, Sokoto, Bauchi, Maiduguri, Zaria, Kaduna, Kebbi, Yola, Potiskum, Katsina, and Zamfara. The southern sites are Edo, Abuja, Calabar, Warri, Ilorin, Osun, Kogi, Oyo, Ogun, Enugu, Onitsha, Ondo. The distribution of all the sites on the map of Nigeria is as shown in Figure 1.

The available sites are well distributed to give a wide geographical coverage and appropriate description of the needed information. Four months representing the four meteorological climate seasons are considered. Applying equations 4, 5 & 6, measured data of atmospheric variables such as temperature and relative humidity for each site were used to evaluate the wet term of tropospheric refractivity. The median values of wet refractivity were considered instead of the mean values in order to avoid the effect of extreme values on the results.

Nigeria being a tropical region has two seasons – the wet and the dry. The wet season is characterized with heavy rainfall. It falls between the months of April and October and the ITU-R representative months for this season are the months of May and August. The dry season, on the other hand, is characterized with scanty or no rainfall and dry dust laden atmosphere. The season lies between the month of November and March. The ITU-R representative months for the dry season are November and February. Results obtained for these four months of the year considered are shown on the same graph to facilitate seasonal comparison.

4. Results and Discussion

The sites in the northern part of the country experience a wide range of average seasonal variation over the year as shown in Figure 2. The values are higher in the raining months of May and August than in the non-raining months of February and November. All northern sites considered have wet term refractivity that fall below 50 N-units in February. Plateau, Sokoto, Maiduguri, Potiskum, Katsina and Zamfara states have values below 50 N-units in the month of November. The highest value for each of the northern sites is observed in the month of August. All the northern sites, except Jos have N-wet value exceeding 100 N-units in the month of August. The intensity of rainfall in the month of August at the peak and the high relative humidity of the atmosphere is observed to be responsible for the high value of N_{wet}. This shows the dependence of N-wet, vis-à-vis the refractivity, of the atmosphere and consequently the radio wave refraction on the water content of the atmosphere. However, there occurred an aberration at Kebbi. The value of N-wet at Kebbi is very high in comparison to other northern sites for all the months under consideration. The N-wet value for Kebbi was also observed to peak in the month of May.

In contrast, Figure 3 shows that the southern sites display little seasonal variation. The N-wet values in the wet and the dry seasons are very close. Moreover, the southern sites show higher N-wet values compared to the northern sites. The wet term refractivity exceeds 100 N-units for all the sites in the month of May, August and November. The minimum value was observed in the month of February for all the southern sites. The N-wet values for Abuja, Ondo, Osun, Ilorin, Kogi, Oyo and Enugu fall below 100 N-units in the month of February.

Nevertheless, the values are higher than 75 N-units for all the sites. The coastal states have values higher than 150 N-units for all the months considered. The highest value of 157.6 N-unit was observed in Warri.

Fig. 1. The map of Nigeria

5. Conclusion

This research work evaluated the wet-term of refractivity in Nigeria. The result describes the wet-term of tropospheric refractivity over twenty three sites in Nigeria and the result can be taken into account as an empirical reference for tropospheric wave propagation, radar measurements and evaluation of amplitude scintillation for satellite communication in Nigeria. The result will also be a useful tool for the systems designer and the respective regulatory agencies.

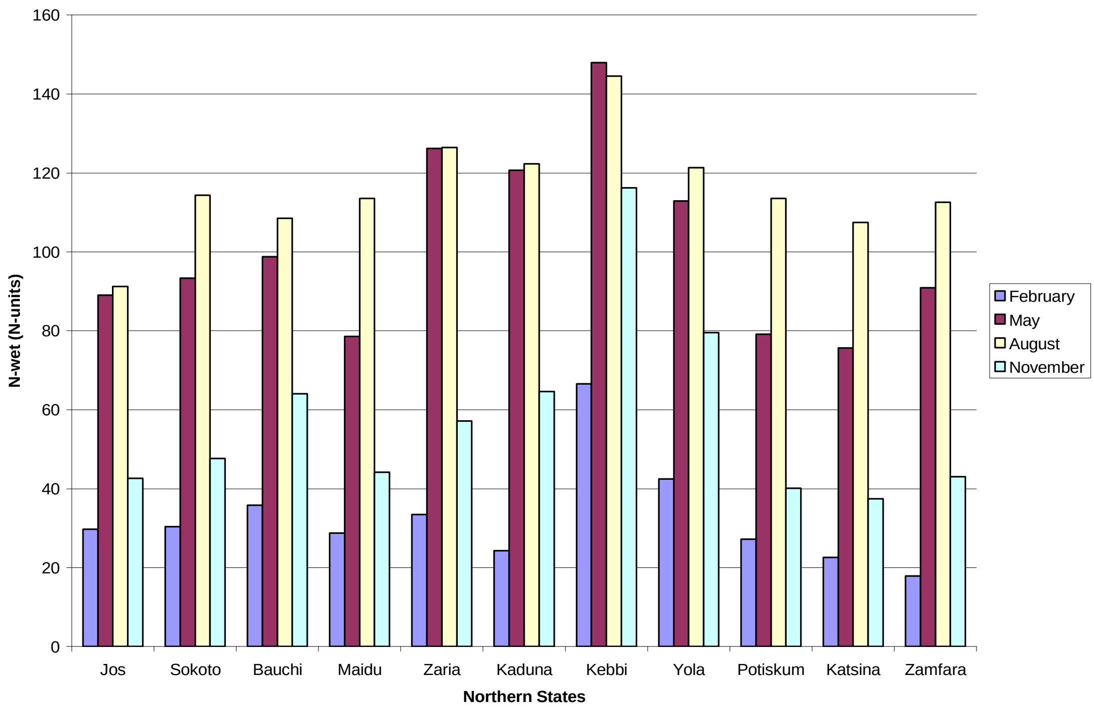

Fig. 2. The Graph of N_{wet} for the Northern States

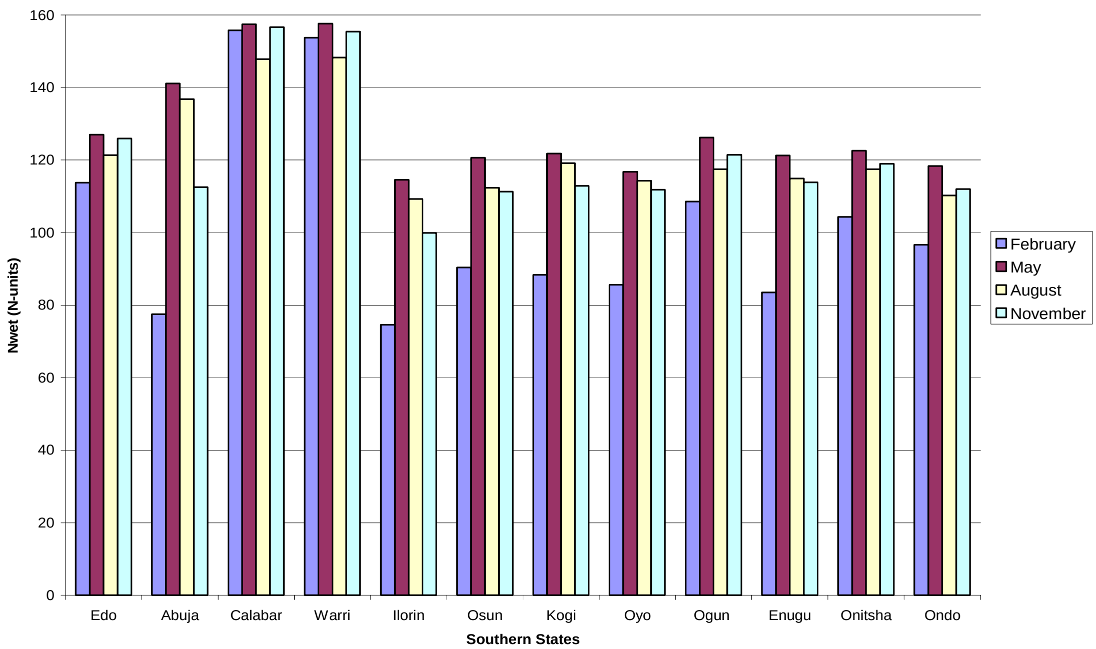

Fig. 3. The Graph of N_{wet} for the Southern States

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