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Probability Distribution Modelling of Microwave Radio Refractivity over Selected Locations in Nigeria

Dada Joseph Babatunde.[1, 2*], Adediji Adekunle Titus.[1], Ogunjo Samuel Toluwalope.[1], Ashidi Ayodeji Gabriel.[1] , and Akinremi Moses Oluwadamilare[1]

[1]*Department of Physics, Federal University of Technology, Akure. P.M.B 704, Ondo State, Nigeria*

[2]*Department of Physical and Chemical Sciences, Elizade University Ilara-Mokin. P.M.B 002, Ondo State, Nigeria*

***Corresponding author: Dada Joseph. B: *babatunde.dada@elizadeuniversity.edu.ng**

Abstract

In this study, distribution models were used to model radio refractivity of some stations across the various climatic zones of Nigeria. Eleven years (January 2004 to December 2014) of Meteorological Data from ERA INTERIM Re-analysis data were used to calculate radio refractivity of each location. It was observed that normal distribution among the probability distribution functions, predicts the peak of the distribution curve and gives the best fit for radio refractivity in all the locations. Weibull distribution strength is built from a small sample sizes. The distribution of the mean value of refractivity in the coastal areas was observed to be weak.

Keywords: climatic zone, distribution models, era interim, meteorological data, normal distribution, radio refractivity.

Headlines: Introduction, Results and Discussion, Conclusions, Experimental Section, Know-How Transfer

Introduction

The propagation of electromagnetic waves in the atmosphere is significantly affected by the composition of the atmosphere (Korak, 2003). This upset is due to the fluctuations of atmospheric parameters like temperature, pressure and relative humidity primarily in the troposphere and the troposphere is usually referred to as "the lower" part of the earth. The fluctuation of the atmospheric parameters results in the refractivity variation in the lower atmosphere that causes the refractive index of the air in this layer to vary from one point to the other (Dada, 2019). The refractivity that determines how radio wave propagates in the atmosphere depends on the physical structures of the atmosphere (Olasoji and Kolawole, 2011). The degree of accuracy of atmospheric parameters measurements is usually a function of care exercised by the observer and the sensitivity of the equipment used (Adedokun, 1978) because the calculation of the refractive index is based on a result created by the atmospheric parameters. The refractive index is responsible for bending of the propagation direction of the electromagnetic wave (Guanjun and Shukai, 2000).

Trajectory change of radio wave in the troposphere is as a result of the vertical variations of the refractive index and its gradient (Adediji et al., 2019). Multipath effects occur as a result of large-scale variations in atmospheric radio refractive index, such as different horizontal layers having different refractivity (Grabner and Kvicera, 2009). Refractivity is responsible for various phenomena in the wave propagation such as ducting and scintillation (Grabner and kvicera, 2003), refraction and fading of electromagnetic waves (Babin, 1996), range and elevation errors in radar acquisition (Lowry *et al.*, 2002). In recent times, communication had advanced to the point in which people need to communicate with voice and video at any time (Duraimurugan and Jayarin, 2015).

Computer networking is mainly for data sharing and the ability of the user to communicate. This process is achievable through what is called media transmission which could either be a guided medium (Cable) or unguided medium (wireless). The wireless medium is through the atmosphere, and it makes the networking environment to be neater because less cable is required (Priya and Gurjot, 2016). The consideration of the refractive properties of the lower atmosphere is of great importance when planning and designing terrestrial communication systems mainly because of multipath fading and interference due to horizon propagation.

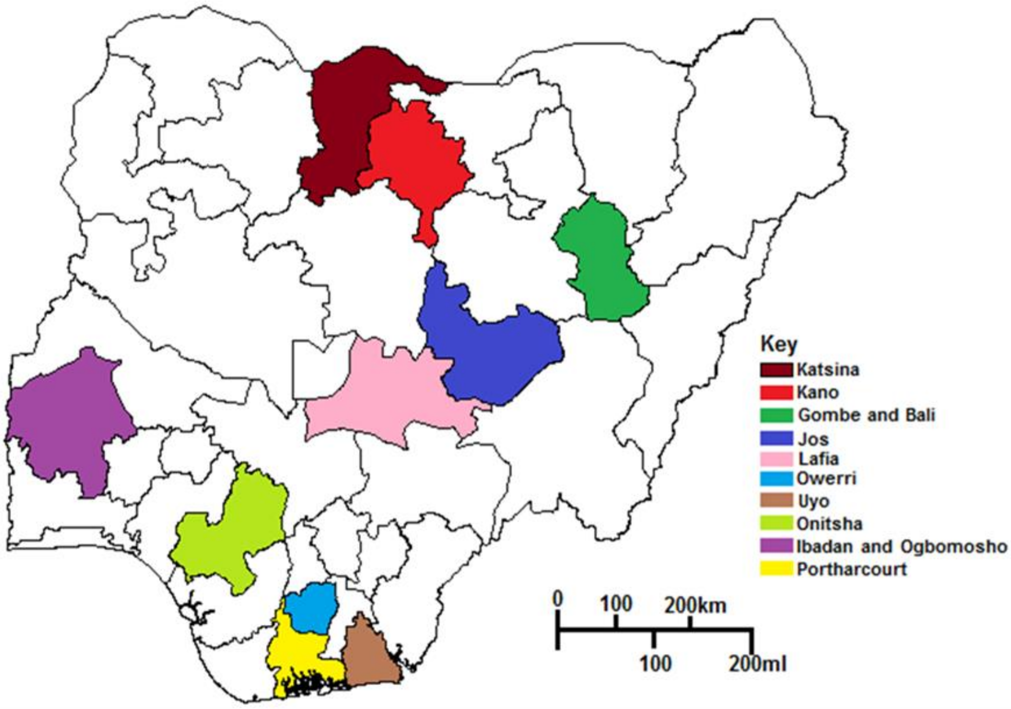

Fig. 1. Map of Nigeria showing the location of the study areas

In this regard, the most studies that have worked on the statistical modelling tools is yet to provide the best modelling tools for predicting the maximum distribution value of refractivity. Taking into account the nature of radio propagation situation in some locations in Nigeria (Fig. 1), different probability distributions; Normal distribution, Tlocation-Scale distribution and Weibull distribution were used to model the statistical behavior of the refractivity in Nigeria. The objectives of this study are to know the distribution pattern of radio refractivity of the locations and determine the best probability distribution for the prediction of peak radio refractivity spread in the selected area.

Distribution related to the Central Limit Theorem

The Theorem stated that sample means and sample sums approach normal distributions as the sample size approaches infinity. The Normal distribution also called the Gaussian distribution is ubiquitous in probability and statistics (Murray and Stephens, 2008). An actual normal distribution curve must conform to specific rules concerning its standard deviation, an expression of the amount of which the value of a frequency/functions is being distributed or concentrated. A small value of the standard deviation produces a sharp curve with a narrow peak and steep sides. A tremendous amount of it shows a large curve with less steep sides, and if it approaches zero, the curve becomes narrower while the curve becomes almost flat when the standard deviation becomes arbitrarily large (Ross, 2010).

The Tlocation-Scale distribution is useful for modeling data distributions with heavier tails (more prone to outliers) than the normal distribution. It approaches the Gaussian distribution as the degrees of freedom (ν) approaches infinity, and smaller values of ν yield the heavier tails (Murray *et al.*, 2001). The Weibull distribution fits well with experimental fading channel measurements, for both indoor and outdoor propagation environments. It is a continuous random variable that is often used to model the time until the failure of a physical system (Montgomery and Runger, 2010).

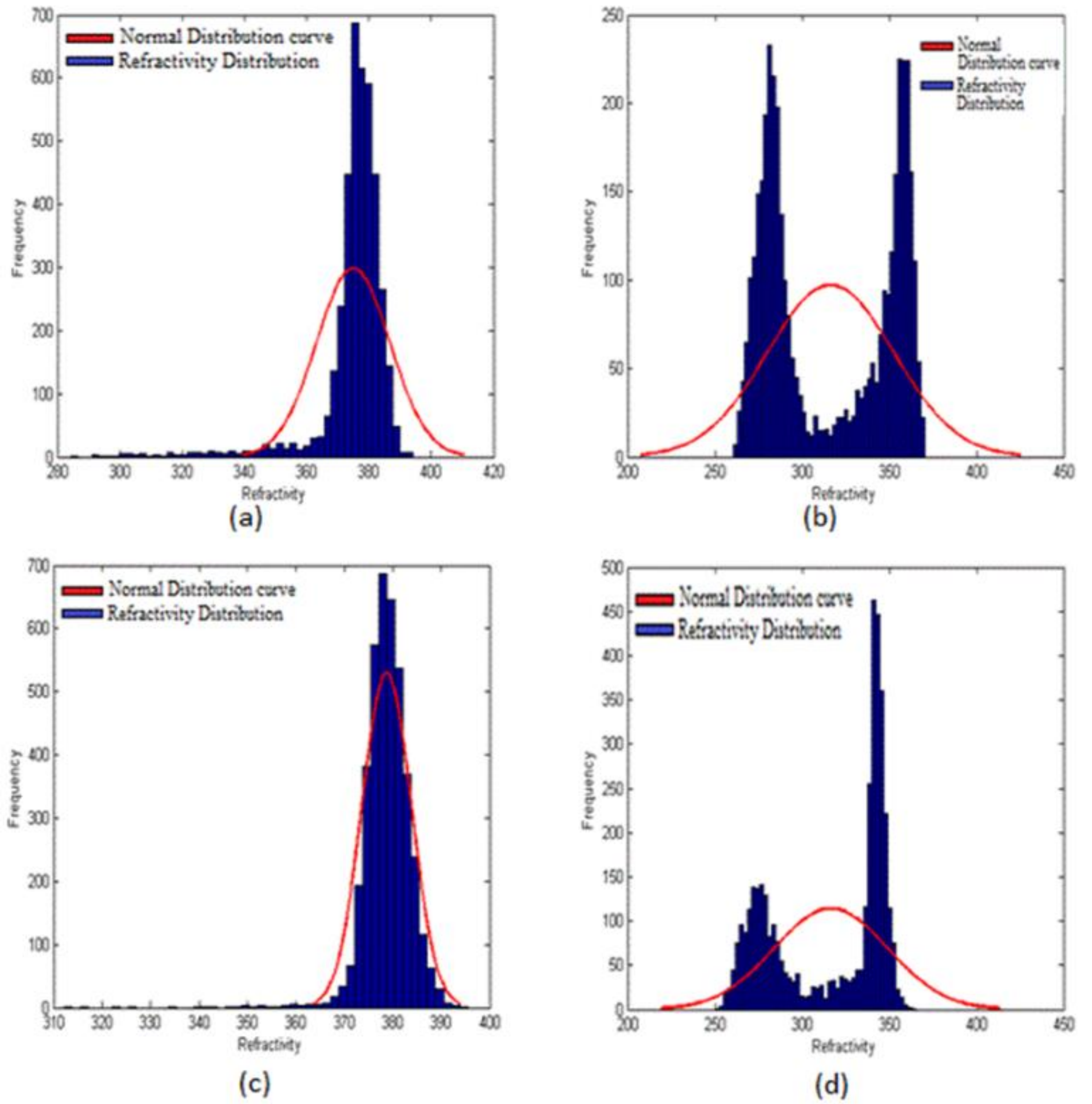

Fig. 2: Normal probability distribution curve for (a) Ibadan (b) Kano (c) Uyo (d) Jos

Results and Discussion

One station was considered from each of the climatic region under consideration in Nigeria for a typical result that described the main observation of each of the standard probability distribution across the entire climatic region. The frequencies (number of occurrences) of the refractivity were plotted against the refractivity of each location, in this regard refractivity was observed to range between 250 to 400 N-unit across all the stations studied.

Figure 2(a - d) shows the Normal probability distribution of stations under consideration with a shape of symmetrical frequency curve assuming a fact of equidistant observation of the refractivity distribution from the central maximum having the same frequency. The degree of the peak of the refractivity distribution ranges from 100 to 550. The dumbbell across three stations (fig.2a-b, d) which is almost flat top and symmetrical shape (Mesokurtic) indicates the normal

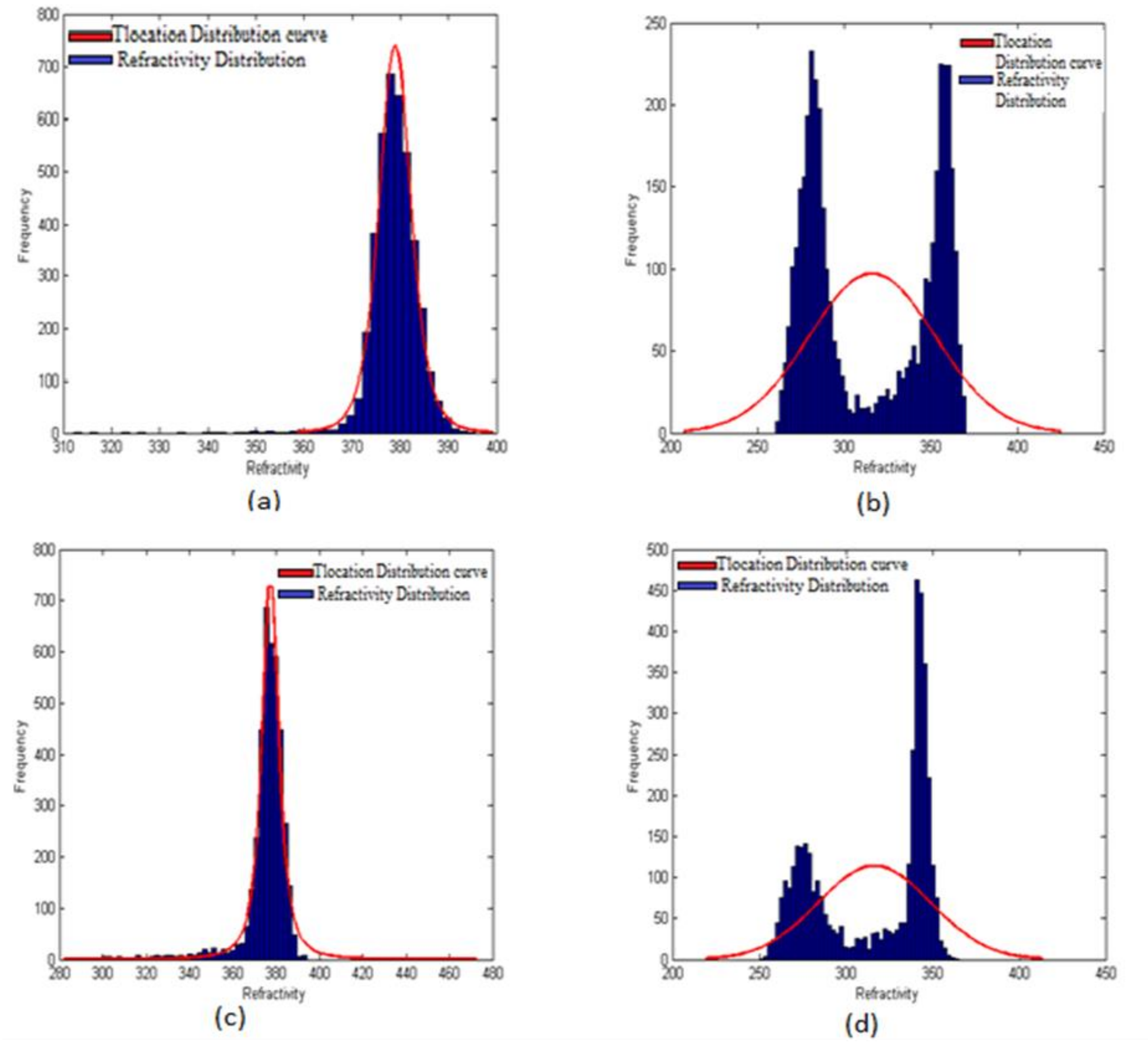

Fig. 3: Tlocation-Scale probability distribution curve for (a) Ibadan (b) Kano (c) Uyo (d) Jos

distribution and arbitrarily large value of the standard deviation. This indication implies a proper spread out of the mean value of refractivity while the dumbbell at Uyo with a symmetrical shape like other stations give a narrow peak and steep sides (Leptokurtic), this observation of Uyo could be linked to the location of the station.

The frequency (number of occurrences) against the refractivity plot of the location (fig. 3a – d) describes the Tlocation-Scale distribution of the stations studied.
Asymmetric frequency curve was observed which approaches the Normal distribution of the locations with the dumbbell shape that skewed to the right (fat tail to the right). This curve defines a positive-departure of the distribution of the refractivity mean values across all the stations. The narrow dumbbell shape at Ibadan and Uyo (fig.3a & c) shows a standard deviation that approaches zero indicating a poorer distribution while at Kano and Jos it is relatively flattened (Mesokurtic) depicting large values of the standard deviation. The implication is a well spread out of the distribution around the norm mean value of refractivity

The Weibull probability distribution (Fig. 4a - d) assume the characteristic of normal distribution dumbbell curve that skewed to the right (fat tail to the right) depicting a progressive departure of the distribution from the refractivity mean values across all the stations. The degree of the peak of the refractivity distribution ranges from 100 to 600. Similarly to Tlocation distribution, the

Weibull probability distribution shows a dumbbell shape for Ibadan and Uyo with a narrow peak (Leptokurtic) and steep sides. The observation indicates a small value of the standard deviation, while at Kano and Jos it is relatively flattened (Mesokurtic) depicting large values of the standard deviation implying a well spread out of the distribution around the normal mean value of refractivity.

Conclusions

Refractivity has been modeled using distribution models for two stations each from the climatic zones in Nigeria. It was observed that the standard probability distribution functions used, that is, Weibull, Normal and Tlocation-Scale distributions are adequate for some stations and inadequate for others, despite this fact, the Normal distribution function gives the best fit of the

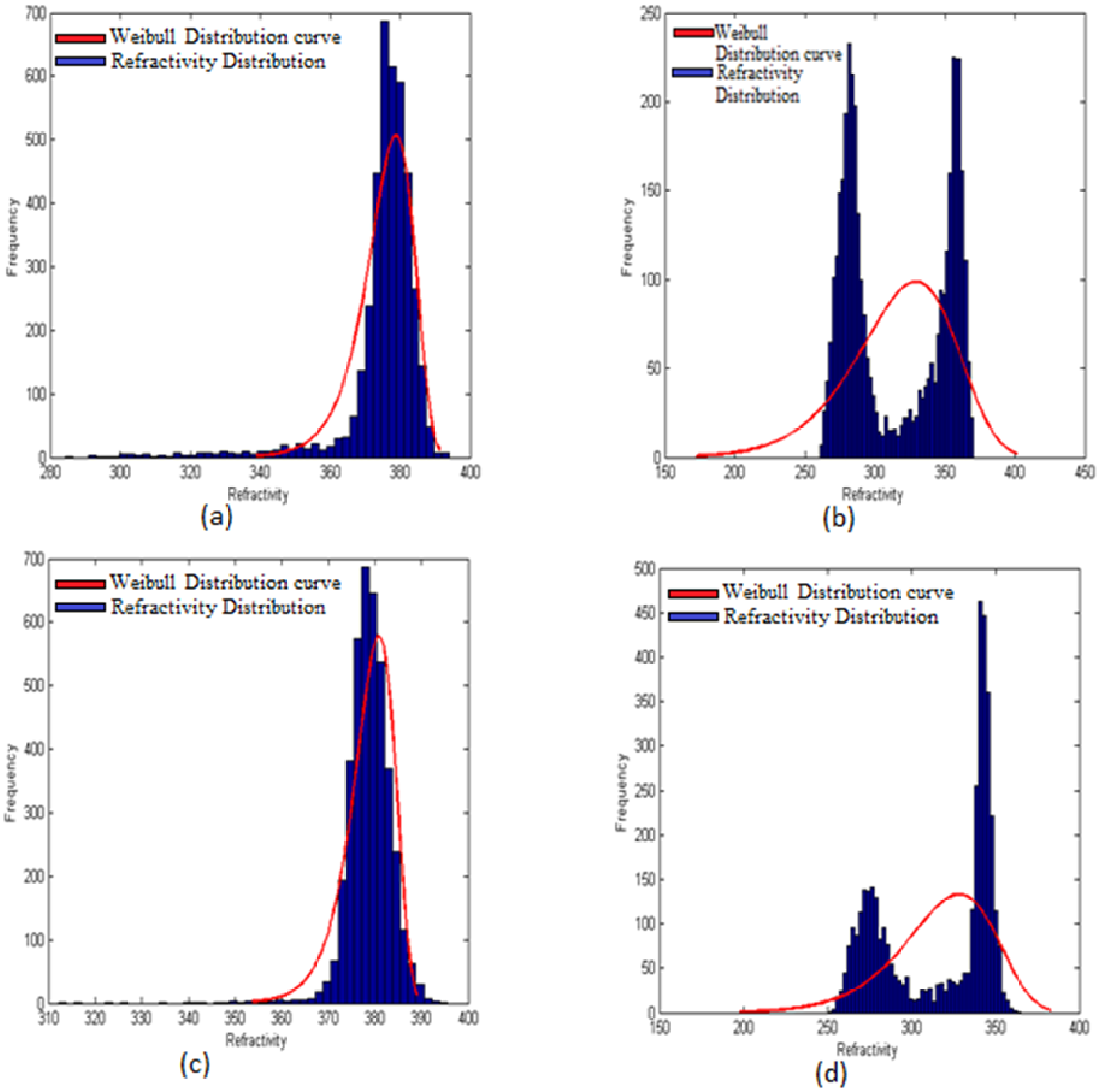

Fig. 4: Weibull probability distribution curve for (a) Ibadan (b) Kano (c) Uyo (d) Jos

distribution curve. The Tlocation-Scale tends to follow the Normal but has a heavier tail to the right. The standard deviation of the distribution at coastal zone is relatively small which is described by a narrow dumbbell shape by all distribution models used, and it implies weak distribution around the standard mean value of the refractivity. This implication could be associated with the seasonal variation in these locations that is characterized by the extensive rainy season and short dry season which is in agreement with (Emmanuel et al., 2013).

In accordance to (Todinov, 2009), the inability of Weibull model for the prediction of the peak of refractivity in this study could be linked to the fact that the Weibull is a mathematical formulation of the weakest-link concept. Also in support of (Danzer, 2006) and (Danzer et al., 2007) that in almost any case the Weibull distribution strength is built from limited/narrow sampling sizes compared to that used in this study (January 2004 to December 2014).

Experimental section

Meteorological Data, temperature, pressure and dew point of Eleven years spanning from January 2004 to December 2014 for twelve locations were downloaded from ERA INTERIM and used to compute the radio refractivity of the locations. The equation 1 was used to convert Dew point to relative humidity by (Lawrence, 2005):

$$RH = 100 - 5(t - t_d) \qquad (1)$$

where t is ambient temperature, t_d is dew point temperature (°C), and RH is relative humidity in percentage.

Water vapour pressure e was determined from the relative humidity and saturated water vapour from (Adediji and Ajewole, 2008):

$$e = H \times \frac{6.1121 \exp(\frac{17.502\, t}{t + 240.97})}{100} \qquad (2)$$

The radio refractivity N is computed using (Adediji *et al*., 2015):

$$N = 77.6 \frac{p}{T} + 3.73X10^5 \frac{e}{T^2} \qquad (3)$$

where: e = water vapor pressure (hPa), p = atmospheric pressure (hPa), T = absolute temperature (K), H = relative humidity (%), and t = temperature (°C).

The standard probability distribution functions used in the work that is Normal, Tlocation and Weibull, scale distributions are as follows:

Normal Distribution: The normal distribution is given as (Ross, 2010);

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp(-\frac{(x-\mu)^2}{2\sigma^2}),\ for \to x \in R$$

$$\mu = \mu..\sigma^2 = \sigma^2.$$

$$m(t) = \exp\left(\mu t + \frac{t^2\sigma^2}{2}\right). \qquad (4)$$

where the parameters μ the mean and σ the standard deviation of the distribution are real numbers, being positive with positive square root σ.

Tlocation-Scale Distribution : (Murray *et al*., 2001):

$$f(x|\mu,\sigma,v) = \frac{\tau(\frac{v+1}{2})}{\sigma\sqrt{v\pi}\,\tau(\frac{v}{2})}\left[\frac{v + (\frac{x-\mu}{\sigma})^2}{v}\right]^{-(\frac{v+1}{2})} \qquad (5)$$

where v is degrees of freedom, τ is a gamma function.

Weibull Scale random variables: (Montgomery and Runger, 2010).

$$f(x|a,b) = \frac{\beta}{\delta}\left(\frac{x}{\delta}\right)^{\beta-1} e^{-(x/\delta)^{\beta}} \quad ; \quad x > 0 \qquad (6)$$

where δ is the scale parameter stored as a positive scalar value and $ß$ is the shape parameter stored as a positive scalar value.

Know-How Transfer

This study has been able to establish the best distribution pattern of radio refractivity and the probability model for the prediction of peak radio refractivity spread in the selected location in Nigeria. Equation 1 – 3 has been employed to convert Dew point to relative humidity, determine water vapor pressure from relative humidity and saturated water vapor, and compute radio refractivity respectively while the standard probability distribution functions used in the work which include the Normal, Tlocation scale and Weibull scale distributions has been fully described in equation 4 – 6 of the study. This work will help radio engineer to be able to know the distribution pattern and the predict peak of radio refractivity spread in the selected location.

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