Progress In Electromagnetics Research Letters, Vol. 64, 37–41, 2016

Statistical Investigation of Clear Air Propagation in the Coastal and Plateau Regions of Nigeria

Israel Emmanuel* and Babatunde Adeyemi

Abstract—The long-term meteorological data of Era-interim from 1979 to 2014 covering the observation at 00, 06, 12 and 18 UTC have been used to derive vertical refractivity gradient in the lowest 100. Diurnal, seasonal and annual variations of refractivity gradient and its component are analyzed for coastal and plateau areas of Nigeria. The relative frequency of the occurrence of gradient below −100 N-units/km used in clear air propagation study is derived from cumulative distribution of the gradient. Occurrence of anomalous propagation in each region is also estimated. The result will help in the effective wireless link planning and design.

1. INTRODUCTION

Electromagnetic signals propagating through the atmosphere interact with its molecules through absorption and scattering of EM energy [1]. Its significance in the atmospheric refractive index is that the signal propagating through the troposphere will bend towards the earth [2]. This interaction causes adverse effects such as multipath fading, interference and attenuation of radio signal which significantly impair radio communication, navigation and radar systems [3, 4]. Several works on refractivity and its effects have been carried out in some selected locations in Nigeria using radionsonde and in situ data [2–6]. However, due to unavailability of data, plateau area of Nigeria has not been well studied. Era-interim reanalysis data are used in this study because of their high spatial and temporal resolution. ERA-interim [7] is the European Centre for Medium-Range Weather Forecast's (ECMWF's) current comprehensive atmospheric reanalysis. It is built on a version of the ECMWF forecasting system operational in 2006, with horizontal grid resolution of around 80 km and a 60-level vertical resolution extending to 0.1 hPa. The 36-year period from 1979 to 2012 is studied here.

2. CALCULATION OF RADIO REFRACTIVITY AND REFRACTIVITY GRADIENT

The refractive index of air is close to unity and defined in term of refractivity, N, as [8–11]:

$$N = (n-1)\times 10^6 = \frac{77.6}{T}\left(P + \frac{4810e}{T}\right) \tag{1}$$

where T is the absolute temperature (K), P the pressure (hPa) and e the water vapour (hPa). The dry, N_d, and wet components, N_w, of refractivity are expressed as:

$$N_{dry} + N_{wet} = \frac{77.6P}{T} + \frac{3.73\times 10^5 e}{T^2} \tag{2}$$

Received 29 September 2016, Accepted 3 November 2016, Scheduled 23 November 2016
* Corresponding author: Israel Emmanuel (iemmanuel@futa.edu.ng).
The authors are with the Department of Physics, Federal University of Technology, Akure, Nigeria.

e can be calculated from relative humidity, $H(\%)$, and saturation water pressure e_s (hPa) and temperature, t, (°C) [12, 13] using:

$$e_s = a \exp\left(\frac{bt}{t+c}\right) \tag{3}$$

$$e = \frac{He_s}{100} \tag{4}$$

$$e = H \times \frac{6.1121 \exp\left(\frac{17.502t}{t+240.97}\right)}{100} \tag{5}$$

Refractivity gradient G is obtained from surface refractivity N_s, and refractivity N_1, at any height h_1 above the surface level h_s using the following relation [14]:

$$G = \frac{N_s - N_1}{h_s - h_1} \text{ (N-units/km)}. \tag{6}$$

The vertical variation of N determines the degree of refraction of the radio signal. Under the standard conditions, refractivity gradient is assumed equal to -40 N-units/km with effective earth radius factor, $k = 4/3$, here radio signal travels in a straight line. Departure from this value is not unusual, and the radio signal behaviour is termed anomalous. During sub-refraction, radio signal is bent less than usual ($G > 0$ N-units/km) which causes radio horizon to decrease. Under super refractions, $-78 > G < -157$ N-units/km and radio signal will extend the path of the beam, possibly beyond the usual transmission horizon. Ducting is an extreme of anomalous propagation where $G < -157$ N-units/km, and radio signal is trapped in a layer where propagates as in a wave guide [15].

3. RESULT AND DISCUSSION

The monthly mean values of N_w/N, N_d/N and N_d/N_w for Coastal (Lagos) and Plateau (Jos) are shown in Figure 1. The dry component contributes about 70% of the overall value of refractivity, while the variation in refractivity is associated with wet component [16]. In coastal region, N_d/N values oscillate

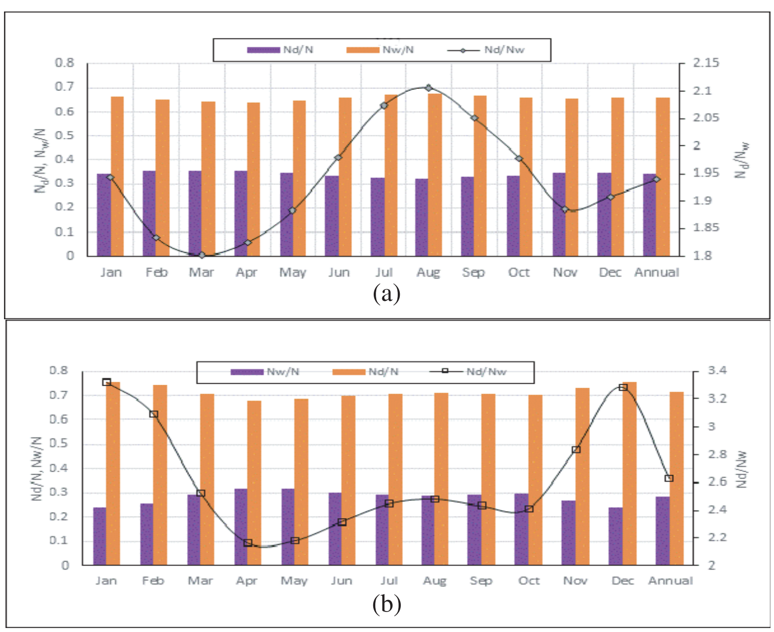

Figure 1. The monthly distribution of N_d and N_w components relative to the N value and N_d/N_w in (a) Coastal and (b) Plateau region of Nigeria.

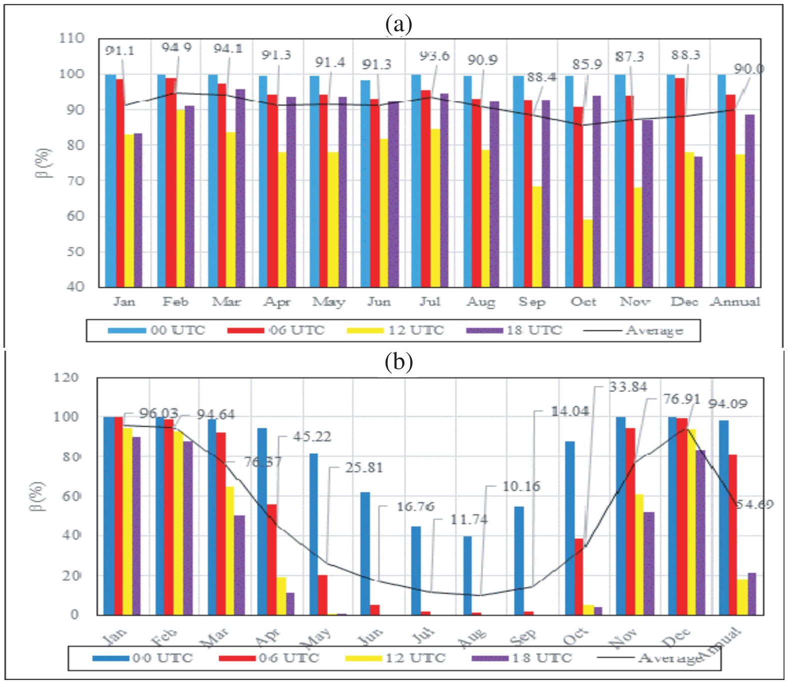

Figure 2. The β_o values corresponds to 00 UTC, 06 UTC, 12 UTC, 18 UTC and its average for each month and the whole year in (a) Coastal and (b) Plateau.

between 0.35 and 0.32 with a range of 0.03 units. Values of N_w/N and N_d/N_w oscillate between $0.67 \sim 0.634$ and $2.10 \sim 1.802$ with range of 0.03 and 0.30 unit, respectively. Two deeps are discernible in the monthly variation of N_d/N_w at coastal region, associated with the onset and peak of dry season in this region, with a peak observed in August. August peaks may be linked to the August break (a period of short dry season) associated with the movement of inter-tropical discontinuity (ITD) [17]. From Figure 1(b) (Plateau region), $N_d/N, N_w/N$ and N_d/N_w oscillate between $0.75 \sim 0.68$, $0.24 \sim 0.32$ and $2.16 \sim 3.32$ with range of 0.07, 0.08 and 1.16 units respectively. Unlike coastal region, two peaks are obtained in monthly distribution of N_d/N_w, a conspicuous one in the dry season (December–January) and a minor peak in August. The little peak in August may be attributed to August break.

β_o factor is the percentage of time refractivity gradient in the lowest 100 m above the ground, less than -100 N-units/km. It plays a vital role in investigating clear air propagation and interference and is used to show the relative frequency of anomalous propagation [18]. Figure 2 depicts the monthly and annual distributions of β_o values at 00, 06, 12 and 18 UTC in coastal and plateau region. This parameter is commonly used to study clear air propagation and interference associated with relative incidence of anomalous propagation. It represents the percentage time in which the value of G is less than or equal to -100 N-units/km [18] and derived from cumulative distribution of refractivity gradient in the lowest 100 m of the atmosphere. In coastal region, maximum β_o is observed at 00 UTC (midnight), which varies in the range of $100 \sim 98\%$ throughout the year. At 06 UTC, the yearly variation of β_o is between

Table 1. Mean values of refractivity compared with ITU maps.

	N (N-units)		G (N-nits/km)	N_{dry} (N-units)	N_{wet} (N-units)
	Calculated Value	ITU Value			
Lagos (Coastal)	399	380	-277	263	137
Jos (Plateau)	372	335	-176	265	107

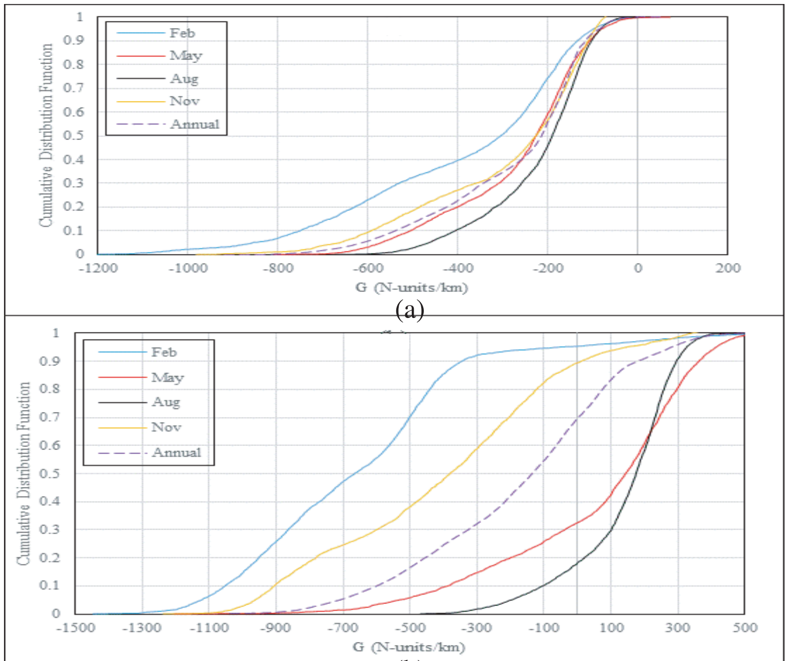

Figure 3. Annual and monthly cumulative distribution function of refractivity gradient at (a) Coastal and (b) Plateau.

90% and 94%. Conversely, at 12 UTC, it oscillates between 59 and 89%. The average monthly diurnal variation is between 84 and 94% (Figure 2(b)). At plateau region (Figure 2(b)), β_o value follows seasonal trend with the highest and lowest values of β_o observed in dry and wet seasons, respectively. At 00, 06, 12 and 18 UTC, values of β_o vary between 99 $\sim$ 39, 99 $\sim$ 1, 94 $\sim$ 0 and 89 $\sim$ 0%, respectively. The average variation oscillates between 96 and 10%. This result shows that high percentage of super refraction and ducting phenomenon will be experienced at 00 and 06 UTC with reduction at 12 UTC in coastal region. This occurrence will only be high at 00 and 06 UTC, and low at 12 and 18 UTC during the dry season. It will, however, disappear at 12 and 18 UTC during the rainy season in plateau region (Figure 2(b)). During the ducting phenomenon, radio signal will be trapped and result in multipath fading and interference.

Calculated refractivity values are compared with ITU values [8] in Table 1. The estimated ITU values of N are below those calculated. It may be ascribed to the fact that the ITU maps in [8] were interpolated from 99 stations worldwide of radiosonde data from 1955 to 1959. Average values of G for the two locations with absolute N_{dry} and N_{wet} are also shown in Table 1.

Figure 3 indicates long-term monthly and annual cumulative distribution functions of G in coastal and plateau regions. Cumulative distribution functions (CDF) of refractivity gradient are of special interest in terrestrial microwave planning. There is significant variation in the observed values during the course of the year as shown in Figure 3. In coastal region, the probability of ducting occurrence in February, May, August and November are 0.85, 0.76, 0.65 and 0.67, respectively (Figure 3(a)). On the other hand, in plateau area, it is 0.94, 0.22, 0.69 and 0.70, respectively (Figure 3(b)).

4. CONCLUSION

Era-interim data of thirty six years are analyzed to obtain refractivity and its gradient at 100 m altitude above the ground for coastal and plateau regions of Nigeria. Analyses of monthly refractivity component relative to refractivity are observed. Monthly and annual variations of β_o-factor are also investigated. High variation of β_o with little monthly variation is associated with coastal region of Lagos at 00 UTC and 06 UTC. β_o trend in plateau region experiences high seasonal variation with maximum value obtained in dry season at 00 and 06 UTC. Values of β_o range between 59% and 79% at 12 and 18 UTC during the rainy season in coastal region, whereas the values tend to zero in plateau region during this period, indicating absence of ducting. Cumulative distribution of G shows high and low probabilities of ducting in coastal and plateau, respectively. This result will assist radio link engineers in radio planning and design.

REFERENCES

1. Karmakar, P. K., L. Sengupta, M. Maiti, and C. F. Angelis, "Some of the atmospheric influences on microwave propagation through atmosphere," *American Journal of Scientific and Industrial Research*, Vol. 1, No. 2, 350–3458, 2010.
2. Adediji, A. T. and M. O. Ajewole, "Vertical profile of radio refractivity gradient in Akure South-west Nigeria," *Progress In Electromagnetics Research C*, Vol. 4, 157–168, 2008.
3. Lavergnat, J. and M. Sylvain, *Radio Wave Propagation: Principles and Techniques*, John Wiley & Sons, ISBN 0-471-49027-X Chichester, UK.
4. Adeyemi, B. and I. Emmanuel, "Monitoring tropospheric radio refractivity over Nigeria using CM — SAF data derived from NOAA — 15, 16 and 18 satellites," *Indian Journal of Radio and Space Physics*, Vol. 40, 301–310, 2011.
5. Adeyemi, B., "Tropospheric radio refractivity over three Radiosonde Stations in Nigeria," *Ife Journal of Science*, Vol. 6, No. 2, 167–176, 2004.
6. Willoughby, A. A., T. O. Aro, and I. E. Owolabi, "Seasonal variations of radio refractivity gradients in Nigeria," *Journal of Atmospheric and Solar-Terrestrial Physics*, Vol. 64, 417–425, 2002.
7. Dee, D. P., E. Kallen, A, J. Simmons, and L. Haimberger, "Comments on Reanalysis suitable for characterizing long-term trends," *Bull. Amer. Meteorol. Soc.*, Vol. 92, 65–70, 2011.
8. ITU-R P.453, "The radio refractivity index: Its formula and refractivity data," International Telecommunication Union, Geneva, 2012.
9. Elgered, G., H. P. Plag, H. Van der Marel, S. Barlag, and J. Nash, "COST-716, 2004: Exploitation of ground-based GPS for operational numerical weather prediction and climate applications," *Institute of Applied Physics, University of Bern*, 8–9, 2005.
10. Ruger, J. M., "Refractive index formulae for radio waves," *Proceedings, FIG XXII International Congress, Washington DC*, Apr. 19–26, 2002.
11. Thayer, G., "An improved equation for the radio refractive index of air," *Radio Science*, Vol. 9, No. 10, 803–807, 1974.
12. Sonntag, D., "Important new values of the physical constants of 1986, vapour pressure formulations based on the ITS-90 and psychrometer formulae," *Zeitschrift für Meteorologie*, Vol. 40, No. 5, 340–344, 1990.
13. Buck, A. L., "New equations for computing water vapor pressure and enhancement factor," *J. Appl. Meteor.*, Vol. 20, 1527–1532, 1981.
14. Dominguez, M. A., A. Benarroch, and J. M. Riera, "Refractivity statistics in Spain: First results," COST 255, CP52004, May 1998.
15. Manning, T., "Microwave radio transmission design guide," *Artech House Microwave Library*, 2nd Edition, 129–224, 2009.
16. Adediji, A. T., M. O. Ajewole, S. E. Falodun, and O. R. Oladosu, "Radio refractivity measurement at 150 m altitude on TV tower in Akure, south-west Nigeria," *Journal of Engineering and Applied Sciences*, Vol. 2, No. 8, 1308–1313, 2007.
17. Adedokun, J. A., "West African precipitation and dominant atmospheric mechanisms," *Arch. Met. Geoph. Biokl., Ser. A*, Vol. 27, 289–310, 1978.
18. AbouAlmal, A., R. A. Abd-Alhameed, S. M. R. Jones, and H. Al-Ahmad, "New methodology for predicting vertical atmospheric profile and propagation parameters in subtropical arabian gulf region," *IEEE Trans. Antennas Propag.*, Vol. 63, No. 9, 4057–4068, Sep. 2015.