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Statistics of vertical refractivity gradient over Akure, Nigeria

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Abstract

Vertical radio refractivity gradient is an important factor for the design and planning of microwave communication links. In this work, radio refractivity and distribution of vertical radio refractivity gradient at different times of the day over a tropical station was studied using the ECMWF dataset. Results obtained showed that the refractivity values were higher during the wet season but lower in the dry season. The various probability of occurrence of sub-refraction, super-refraction and ducting were reported in the region.

1 Introduction

If the earth were an homogenous medium, electromagnetic waves will travel in a straight line with negligible reduction in propagation speed. However, since the atmosphere is inhomogeneous, bending of electromagnetic waves as it passes through the atmosphere causes fading, interference and attenuation. The difference in refractivity values at fixed height gives the vertical refractivity gradient ($\frac{dN}{dh}$). The vertical refractivity gradient is important in the computation of different parameters such as k-factor and β_o etc. The effective earth radius (k-factor) is defined as "the radius of a hypothetical spherical Earth, without atmosphere, for which propagation paths follow straight lines, the heights and ground distances being the same as for the actual Earth in an atmosphere with a constant vertical gradient of refractivity" [1]. β_o is useful in indicating the relative incidence of anomalous propagation [2]. It is defined as the percentage of time in which the value of refractivity gradient is less than or equal to $-100 N/km$ [2].

Falodun and Ajewole [3] studied the radio refractivity conditions over the first 100 meters. The authors reported that the worst propagation conditions are between 1500 - 1800 and 1700- 1900 local time during the dry and wet season respectively. Using two year data set over Akure, Adediji et al [4] reported an average value of -52.8 N-units per km and high values of refractivity during the wet season in the region. Radio refractivity and its vertical profile is subject to random variation that is unpredictable in practice [5]. The unpredictability of radio refractivity and its gradients have been investigated [6, 7, 8, 9, 10]. Three harmonics were reported to be sufficient for the modeling of mean refractivity gradients over Nigeria [11]. The influence of intertropical discontinuity (ITD) on the values of radio refractivity over Nigeria has also been investigated [12]. This study aims to investigate the diurnal and seasonal variation of radio refractivity and vertical radio refractivity gradient statistics within the first $1km$ in a tropical station.

2 Methods

2.1 Data and Study area

Temperature and relative humidity data at four synoptic hours of the day (0000, 0600, 1200 and 1800) were obtained from the ERA-Interim reanalysis product produced by the European Centre for Medium-Range Weather Forecasts (ECMWF) from 2012 - 2016 at 1000 mb and 900 mb pressure levels. The ECMWF dataset has been reported to show reliable prediction for different products at different locations in the world [13, 14]. Using a resolution of 0.25×0.25, data for Akure ($7.25^o N$,$5.25^o E$) were extracted. The ancient city of Akure lies in the southwestern part of Nigeria. It is a tropical location with two distinct seasons (wet and dry) [15].

2.2 Analysis

The tropospheric radio refractivity was computed using the expression proposed by [16]

$$N = 77.6\frac{P}{T} + 3.75 \times 10^5 \frac{e}{T^2} \qquad (1)$$

where P and T are the atmospheric pressure (hPa) and temperature (K) respectively. The water vapour pressure e is computed using the expression

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

where H, and t are the relative humidity (%) and temperature (^oC) respectively.

The vertical refractivity gradient can be defined as the rate of change of refractivity N with altitude [17]

$$\frac{dN}{dh} = \frac{N_2 - N_1}{h_2 - h_1} \qquad (3)$$

where N_2 and N_1 are refractivity values at heights h_1 and h_2 respectively. Equation 4 shows the significance of the value of the vertical refractivity gradient. A consequence of super refraction and ducting is the extension of the radio range, which sometimes leads to radio interference between neighbouring transmission links [3].

$$\frac{dN}{dh} = \begin{cases} > -40, & \text{sub refraction;} \\ = -40, & \text{Normal refraction;} \\ < -40, & \text{super refraction;} \\ < -157, & \text{ducting.} \end{cases} \tag{4}$$

The statistics of important refractivity parameters such as an average vertical gradient are extremely useful in practical design of terrestrial radio paths when the long term statistics of the received signal have to be estimated [18].

The k factor is determined using the expression

$$k = \frac{1}{1 + R\frac{dN}{dh}10^{-6}} \tag{5}$$

where R is the radius of the Earth (km) and dN/dh is the gradient of refractive index.

3 Results and Discussion

The mean monthly values of radio refractivity at 900 mb and different times (0030, 0600, 1200 1800) and the daily averages were computed and the results shown in figure 1. From the result obtained, there were low values of radio refractivity during the dry season which increases to maximum values at the onset of the raining season. This result is in agreement with the works of Adediji and Ajewole [4]. The mean monthly radio refractivity values were lowest at 0600 local time and highest at 1800 hrs local time.

Similar analysis were conducted at 1000 mb pressure levels and the results presented in figure 2. The mean values of monthly radio refractivity were in the range 330 - 395 N- units which is higher than that obtained at the 900 mb pressure level (295 - 335 N- units). The dry months have lower refractivity values than the wet season. Mean values at 1200 and 1800 were found to have the lowest and highest refractivity values respectively.

The monthly variation of refractivity gradient at different times of the day was also considered and result presented in figure 3. Subrefraction was observed at 1200 hrs local time during the month of January and February. During the remaining months of the year, super-refraction were observed to prevail in the region. The cumulative distribution of the vertical gradient of atmospheric refractivity in the region for different times of the day is shown in figure 4. The cumulative distribution is in the range -20 to $-170N/km$. Al-Mal [19] reported a range of -200 to $63N/km$ for Abu Dhabi while a range of -1000 to $600N/km$ was reported in the Gulf region [2]. The yearly cumulative distribution of vertical gradient for the location from they year 2012 till 2016 are presented in figures 5 - 9. Similar trends could be observed in all the years. The cumulative distribution of refractivity gradient at 1200 hrs show distinct characteristics with a smooth curve.

Summary of vertical gradient statistics for different hours of the day and average values are presented in Table 1. The lowest daily values were observed at 1200 hours while 0000 hours and 1800 hours show similar trends. These can be attributed to the high values of relative humidity and intense tropospheric mixing recorded at 0000 hours and 1800 hours. At 1200 hours, the activity of the sun is at a maximum, hence, low relative humidity values [20]. Values obtained were slightly different from the ITU recommended values [21]. The variations might be attributed to the resolution of the data used and temporal consideration. The hourly values of β_0 were also presented. β_0 values corresponds to the probability of having refractivity gradient less than or equal to $-100N/km$. From the results presented, refractivity gradient is expected to be less than or equal to $-100N/km$ about 6%, 5%, 2% and 0.88% at 0000, 0600, 1800 and daily averages respectively. The values of refractivity gradient is not expected to be less than $-100N/km$ at 1200 hours. Using the values of refractivity gradient at 50% percentage of occurrence as the median value of k ($k_{50\%}$) [22], values in the range 1.49 - 1.74 were obtained. These values are higher than the 1.33 obtained for a standard atmosphere.

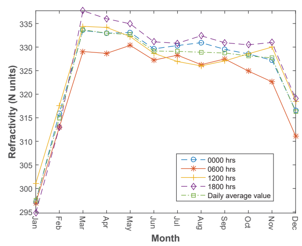

Figure 1. Monthly variation of radio refractivity at 900 mb for different synoptic time of the day.

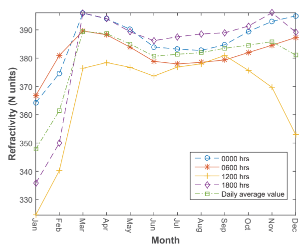

Figure 2. Monthly variation of radio refractivity at 1000 mb for different synoptic time of the day.

4 Conclusion

In this research, we investigated the monthly and yearly variation of radio refractivity over a tropical location, Akure

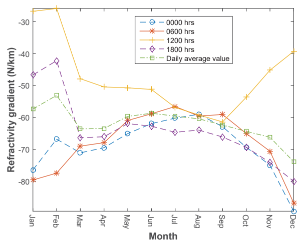

Figure 3. Variation of monthly value of refractivity gradient at the different synoptic times in Akure.

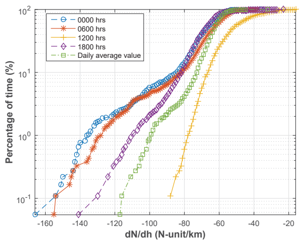

Figure 4. Cumulative distributions of the vertical gradient of atmospheric refractivity over Akure from 2012 - 2016

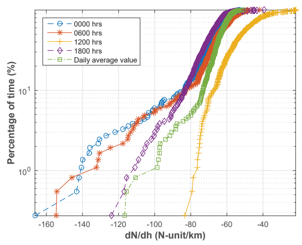

Figure 5. Cumulative distributions of the vertical gradient of atmospheric refractivity over Akure from 2012

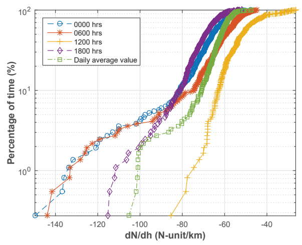

Figure 6. Cumulative distributions of the vertical gradient of atmospheric refractivity over Akure from 2013

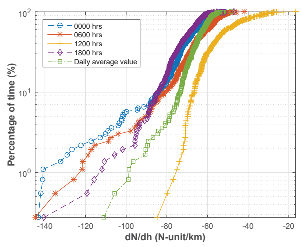

Figure 7. Cumulative distributions of the vertical gradient of atmospheric refractivity over Akure from 2014

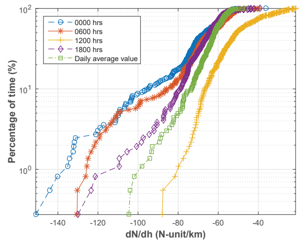

Figure 8. Cumulative distributions of the vertical gradient of atmospheric refractivity over Akure from 2015

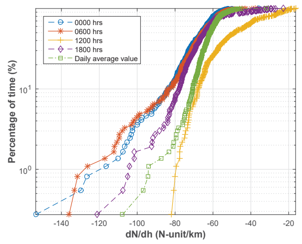

Figure 9. Cumulative distributions of the vertical gradient of atmospheric refractivity over Akure from 2016

Table 1. Values of refractivity gradient for different percentages of time not exceeded and β_0 considering the period 2012 - 2016

	0000hrs	0600hrs	1200hrs	1800hrs	Mean	ITU
1	-135	-126	-77	-109	-99	-86.4
10	-84	-82	-66	-81	-72	-67.4
50	-67	-63	-52	-67	-62	-50.2
90	-57	-53	-31	-57	-56	-32.5
95	-55	-50	-26	-53	-54	-38.5
99	-52	-46	-21	-36	-49	-22.98
β_0	5.75	4.65	NaN	2.08	0.88	
$k_{50\%}$	1.744	1.67	1.50	1.744	1.65	

Southwestern Nigeria. The monthly vertical gradient of refractivity in the first kilometre of the troposphere was also studied, as well as the cumulative distribution of the vertical refractivity gradient at different times of the day. The values of the radio refractivity were highest at 1800 hrs local time while the lowest values were observed at 0600 and 1800 hrs local time at 900 mb and 1000 mb respectively. During the dry season months, the values of radio refractivity were found to be lowest. The vertical radio refractivity gradient were also studied. High values were found at 1200 hrs local time. The cumulative distribution of the vertical radio refractivity shows that ducting occurs about 0.001% of the time in the region at 0000 and 0600 hrs local time. There is the need for continuous observation of communication parameters at high resolution as significant changes occur over time due to changing climate and local climatic conditions.

References

[1] M. I. Skolnik, *Introduction to Radar Systems*. McGraw-Hill, New York, NY, USA, 2001.

[2] A. AbouAlmal, R. A. Abd-Alhameed, K. Al-Ansari, H. Al-Ahmad, C. H. See, S. M. R. Jones, and M. Noras, J, "Statistical analysis of refractivity gradient and β_0 parameter in the gulf region," *IEEE Transactions on Antennas and Propagation*, vol. 61, no. 12, pp. 6250 – 6254, 2013.

[3] S. E. Falodun and M. O. Ajewole, "Radio refractive index in the lowest 100-m layer of the troposphere in akure, south western nigeria," *Journal of Atmospheric and Solar-Terrestrial Physics*, vol. 68, pp. 236–243, 2006.

[4] A. T. Adediji, M. O. Ajewole, and S. E. Falodun, "Distribution of radio refractivity gradient and effective earth radius factor (k-factor) over akure, south western nigeria," *Journal of Atmospheric and Solar-Terrestrial Physics*, no. 73, pp. 2300–2304, 2011.

[5] A. AbouAlmal, 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 Transactions on Antennas and Propagation*, vol. 63, no. 9, pp. 4057–4068, Sept 2015.

[6] A. T. Adediji and S. T. Ogunjo, "Variations in Non-Linearity in Vertical Distribution of Microwave Radio Refractivity." *Progress In Electromagnetics Research M*, vol. 36, pp. 177–183, 2014.

[7] I. A. Fuwape, S. T. Ogunjo, J. B. Dada, G. A. Ashidi, and I. Emmanuel, "Phase synchronization between tropospheric radio refractivity and rainfall amount in a tropical region," *Journal of Atmospheric and Solar-Terrestrial Physics*, vol. 149, pp. 46–51, 2016.

[8] I. A. Fuwape and S. T. Ogunjo, "Quantification of scaling exponents and dynamical complexity of microwave refractivity in a tropical climate," *Journal of Atmospheric and Solar-Terrestrial Physics*, vol. 150, pp. 61–68, 2016.

[9] S. T. Ogunjo, J. S. Ojo, A. T. Adediji, K. D. Adedayo, and J. B. Dada, "Chaos in radio refractivity over Akure, South-Western Nigeria," in *5th Annual Conference of the Nigerian Union of Radio Science (NURS)*, 2013, pp. 56–63.

[10] S. T. Ogunjo, M. O. Ajewole, A. T. Adediji, and J. S. Ojo, "Predicting radio refractivity using a stochastic model," in *URSIGASS 2014*, 2014, pp. 5–8.

[11] A. A. Willoughby, T. O. Aro, and I. E. Owolabi, "Seasonal variations of radio refractivity gradients in nigeria," *Journal of Atmospheric and Solar-Terrestrial Physics*, vol. 64, pp. 417–425, 2002.

[12] B. Adeyemi 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, no. 6, pp. 301–310, 2011.

[13] R. A. Smith and C. D. Kummerow, "A Comparison of in Situ, Reanalysis, and Satellite Water Budgets over the Upper Colorado River Basin," *Journal of Hydrometeorology*, vol. 14, no. 3, pp. 888–905, 2013.

[14] V. Thiemig, R. Rojas, M. Zambrano-Bigiarini, V. Levizzani, A. De Roo, V. Thiemig, R. Rojas, M. Zambrano-Bigiarini, V. Levizzani, and A. D. Roo, "Validation of Satellite-Based Precipitation Products over Sparsely Gauged African River Basins," *Journal of Hydrometeorology*, vol. 13, no. 6, pp. 1760–1783, 2012.

[15] S. T. Ogunjo, A. T. Adediji, and J. B. Dada, "Investigating chaotic features in solar radiation over a tropical station using recurrence quantification analysis," *Theoretical and Applied Climatology*, vol. 127, no. 1-2, pp. 421–427, 2017.

[16] E. K. Smith and S. Weintraub, "The constants in the equation for atmospheric refractive index at radio frequencies," *Proc. IRE*, vol. 41, pp. 1035–1037, 1953.

[17] K. C. Igwe and I. A. Adimula, "Variations of surface radio refractivity and radio refractive index gradients in the sub sahel," *Nigerian Journal of Space Research*, vol. 6, pp. 135–144, 2009.

[18] M. Grabner and V. Kvicera, *Atmospheric refraction and propagation in lower troposphere, Electromagnetic waves*. InTech Europe, 2011.

[19] A. A. Al-Mal and K. Al-Ansari, "Calculation of effective earth radius and point refractivity gradient in uae," *Int. J. Antennas Propag.*, vol. 2010, 2010.

[20] S. Kaissassou, A. Lenouo, C. Tchawoua, P. Lopez, and A. T. Gaye, "Climatology of radar anomalous propagation over west africa," *Journal of Atmospheric and Solar-Terrestrial Physics*, vol. 123, pp. 1 – 12, 2015.

[21] ITU-R, "The radio refractive index: its formula and refractivity data," International Telecommunication Union, Tech. Rep. P.453-10, 2012.

[22] M. Grabner and V. Kvicera, "Refractive index measurement at tv tower prague," *Radioengineering*, 2003.