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Development of Empirical Model for Estimation of the Vertical Profile of Radio Refractivity

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***Abstract*- Values of meteorological parameters vary with altitude. As such, models that can be used to estimate the parameters need to include altitude as one of the variables. In this paper, empirical model is developed for estimating the vertical profile of radio refractivity based on available meteorological data and the altitude at which parameters were obtained. The study was based on Cross River state meteorological data obtained from Radio sounde measurement carried out by Nigerian Meteorological Agency (NIMET). The empirical model estimates radio refractivity as a function of altitude. The model has maximum absolute percentage error of 0.0176%. The model was validated with meteorological data for Akure in the South Western of Nigeria and the model gave maximum absolute percentage error of 0.0849%. The empirical model provides simpler way to determine the vertical profile of radio refractivity from the basic atmospheric parameters, namely, temperature, pressure and relative humidity.**

***Keywords* –Refractivity, Vertical Profile, Radio sonde, Radio climatic Parameters, Wireless Network.**

I. INTRODUCTION

Radio waves travel through the atmosphere as they propagate from the source to the destination [1,2,3,3]. Due to variations in the atmospheric conditions, the radio wave can be reflected, refracted , scattered or even absorbed in the atmosphere [1,2]. Research has shown that the atmospheric parameters vary with altitude; temperature and pressure generally decrease with altitude [4,5,6,7,8,9]. Other atmospheric parameters like wind speed and wind direction as well as relative humidity also vary with altitude but their relationship with altitude is more complex than that of temperature and pressure [10,11,12].

In any case, the vertical variations in the atmosphere are particularly important in the wireless industry as the vertical profile of the atmospheric parameter do have some significant effects on wireless signals. Particularly, the radio signal path is bent as it propagates through the atmosphere due to the variations in the atmospheric parameter with altitude. This phenomenon called refractivity is used to determine the extent to which the radio wave path is bent in the atmosphere as the wave propagates from the transmitter to the receiver [13,14,15,16,18].

Over the years the vertical profile data of the primary atmospheric parameters are obtained using measuring equipment that is launched into the atmosphere or using equipment mounted of communication mast. Based on the measured primary atmospheric or meteorological parameters other secondary meteorological parameters such as refractivity, refractivity gradient and effective earth radius factor are computed. It normally takes several steps of computations before the radio refractivity can be determined and hence other secondary radio climatic parameters that depend on it. In this paper, a simple linear regression model for computing the vertical profile of radio refractivity is developed based on empirical data. The model is validated with data obtained from existing research works published online. In all, the model makes it easier to compute the vertical profile of radio refractivity in one simple formula. It will be useful for wireless network link designers and other disciplines that require information on the vertical profile of radio refractivity.

II. METHODOLOGY

Atmospheric radio refractivity is made up of two components, the wet and the dry component. Each of the two components is determined from the primary climatic parameters, namely; temperature, pressure and relative humidity as follows [18,19, 20, 21]:

$$\mathrm{N_{dry}} = \frac{77.6}{\mathrm{T}}(\mathrm{P}) \qquad (1)$$

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

Where the absolute temperature in Kelvin is T , atmospheric pressure in hPa is p and water vapour pressure is e which is given as:

$$e = 6.112\left(\frac{H}{100}\right)\ \exp\left(\frac{17.5(t)}{t+240.97}\right) \qquad (3)$$

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Where H is the relative humidity in % and t is the atmospheric temperature (Celsius). Then, radio refractivity is given as;

$$N = N_{dry} + N_{wet} \qquad (4)$$

One year (2013) Cross River state meteorological data obtained from Radiosonde measurement carried out by the Nigerian Meteorological Agency (NIMET) was used in the study. The atmospheric temperature (T), atmospheric pressure (P) and relative humidity (U) and altitude (h) were extracted from the meteorological data.

The wet (N_{wet}) and dry (N_{dry}) refractivity components were computed and then the radio refractivity (N) was computed for each set of T, U , P and h. The product of T,U and P (denoted as TUP) is used as one of the variables along with altitude, h to develop a multiple linear regression for estimating the radio refractivity (N) . The model's performance was determined in terms of model absolute percentage error |e%|. Another meteorological dataset from Akure in the South West of Nigeria was used to validate the model.

III. RESULTS AND DISCUSSION

The Cross River state meteorological data for the month of April 2013 is given in Table 1 while Table 2 shows the computed dry component and wet component of radio refractivity and the total radio refractivity for the month of April 2013. The correlation the meteorological parameters and the radio refractivity for the month of April are shown in Table 3.

The correlation values in Table 3 shows that N is highly correlated with all the for parameters, T, U, P , h and TUP. Similar correlation results are obtained for other moths as shown in Table 4 and Table 5 for the months of December and February respectively. Since T, U and P are already part of TUP, a simplified linear regression model is developed with respect to h and TUP.

Table 1 Cross River state meteorological data for the month of April 2013

Altitude[m]	T[C]	U[%]	P[hPa]
0.00	32.50	67.00	1012.60
57.30	30.60	75.40	1006.40
112.10	30.10	73.10	1000.30
167.00	29.50	70.70	994.10
224.40	28.90	68.40	988.00
278.70	28.40	68.80	981.90
331.80	27.90	70.10	975.80
386.90	27.40	71.50	969.20
447.70	26.90	72.90	962.70
511.20	26.40	74.30	956.20
572.00	25.80	75.00	949.90
631.10	25.30	75.50	943.50
691.60	24.80	76.00	937.10
743.00	24.30	76.50	931.70
792.60	23.70	77.50	926.50
839.80	23.30	79.90	921.30
888.10	23.00	82.30	916.20

Table 2 The computed dry component and wet component of radio refractivity and the total radio refractivity for the month of April 2013.

Altitude, h [m]	T[C]	U[%]	P[hPa]	Vapour Pressure	Ndry	Nwet	N
0.00	32.50	67.00	1012.60	32.46	257.21	129.83	387.04
57.30	30.60	75.40	1006.40	32.80	257.24	132.82	390.06
112.10	30.10	73.10	1000.30	30.90	256.10	125.55	381.65
167.00	29.50	70.70	994.10	28.87	255.02	117.78	372.79
224.40	28.90	68.40	988.00	26.98	253.95	110.51	364.46
278.70	28.40	68.80	981.90	26.36	252.81	108.33	361.14
331.80	27.90	70.10	975.80	26.09	251.65	107.57	359.22
386.90	27.40	71.50	969.20	25.85	250.37	106.92	357.28

355.32	353.30	349.86	346.60	343.35	340.39	337.69	337.53
106.21	105.47	103.16	101.15	99.17	97.20	95.37	96.24
249.10	247.83	246.69	245.44	244.19	243.19	242.32	241.29
25.59	25.33	24.67	24.11	23.56	23.02	22.49	22.63
962.70	956.20	949.90	943.50	937.10	931.70	926.50	921.30
72.90	74.30	75.00	75.50	76.00	76.50	77.50	79.90
26.90	26.40	25.80	25.30	24.80	24.30	23.70	23.30
447.70	511.20	572.00	631.10	691.60	743.00	792.60	839.80

Table 3 Correlation among the Meteorological Parameters and The radio Refractivity for the Month of April.

	N	Altitude , h [m]	T[C]	U[%]	P[hPa]	TUP
N	1					
Altitude , h [m]	-0.96706	1				
T[C]	0.995316	-0.98406	1			
U[%]	-0.91343	0.982996	-0.94724	1		
P[hPa]	0.96803	-0.99981	0.984656	-0.98267	1	
TUP	0.995368	-0.93912	0.9817	-0.87045	0.940488	1

Table 4 Correlation among the Meteorological Parameters and The radio Refractivity For The Month of December 2013.

	N	Altitude , h [m]	T[C]	U[%]	P[hPa]	TUP
N	1					
Altitude,h [m]	-0.96706	1				
T[C]	0.995316	-0.98406	1			
U[%]	-0.91343	0.982996	-0.94724	1		
P[hPa]	0.96803	-0.99981	0.984656	-0.98267	1	
TUP	0.995368	-0.93912	0.9817	-0.87045	0.940488	1

Table 5 Correlation among the Meteorological Parameters and The radio Refractivity For The Month of February 2013.

	N	Altitude , h [m]	T[C]	U[%]	P[h.Pa]	TUP
N	1					
Altitude,h [m]	-0.9671	1				
T[C]	0.99532	-0.9841	1			
U[%]	-0.9134	0.983	-0.9472	1		
P[hPa]	0.96803	-0.9998	0.98466	-0.9827	1	
TUP	0.99537	-0.9391	0.9817	-0.8704	0.94049	1

Specifically, the model is developed with the help of Xuru online regression tool. The values of h and TUP are taken as X1 and X2 and the corresponding value of N is taken as Y. The dataset for the various months was pasted in the Xuru Multiple Linear Regression (MLR) textbox and the tool generated the best fit multiple linear regression model based on the dataset pasted. The model is given as;

$$N = 0.0000575[(T)(U)(P)] - 0.014949(h) + 253.5924 \qquad (5)$$

The results of the model's estimation of radio refractivity, N and the model performance for the months of February , April and December are given in Table 6. The maximum absolute percentage error for the months of February, April and December are 0.0099 % , 0.0176 % and 0.0151 % respectively. Also, among the dataset of the 12 months of the year 2013, April had the worst maximum absolute percentage error of 0.0176 %.

Table 7 shows the validation dataset from [22] as well as the actual radio refractivity and the model computed radio refractivity. The results in Table 7 show that the maximum absolute percentage error is 0.0195 %.

Table 6 The Model Performance For The Months of February, April and December.

February			April			December		
N (actual)	N (estimated)	Abs e%	N (actual)	N (estimated)	Abs e%	N (actual)	N (estimated)	Abs e%
371.4	375.1	0.0099	380.2	387.0	0.0176	379.4	385.2	0.0151
361.8	363.9	0.0056	386.1	390.1	0.0102	370.9	374.6	0.0100
357.7	359.4	0.0047	378.3	381.7	0.0088	367.4	370.5	0.0085
356.1	357.4	0.0036	370.2	372.8	0.0071	366.7	369.3	0.0069
354.6	355.4	0.0024	362.4	364.5	0.0057	366.4	368.4	0.0056
353.1	353.4	0.0010	359.6	361.1	0.0043	365.6	367.1	0.0041
350.8	350.7	0.0002	358.2	359.2	0.0028	364.5	365.5	0.0027
348.0	347.6	0.0012	356.8	357.3	0.0012	362.4	363.0	0.0014
344.7	344.0	0.0020	355.3	355.3	0.0000	360.1	360.2	0.0003
341.8	340.9	0.0026	353.7	353.3	0.0010	358.0	357.7	0.0007
338.9	337.8	0.0032	350.6	349.9	0.0021	355.2	354.5	0.0020
331.1	330.2	0.0026	347.7	346.6	0.0030	353.2	352.1	0.0030
317.7	317.0	0.0023	344.7	343.4	0.0039	351.9	350.6	0.0038
308.0	307.2	0.0025	341.9	340.4	0.0046	350.5	349.0	0.0045
311.3	310.1	0.0037	339.5	337.7	0.0053	348.8	347.1	0.0050
314.2	312.7	0.0047	339.5	337.5	0.0059	347.3	345.4	0.0055
319.3	317.6	0.0056	339.9	337.7	0.0064	345.3	343.3	0.0059
Maximum Absolute Percentage Error (%)		0.0099	Maximum Absolute Percentage Error (%)		0.0176	Maximum Absolute Percentage Error (%)		0.0151

Table 7 The Validation Dataset from [22]

Validation Dataset From [22]						
Altitude, h (m)	T (C)	U(%)	P[hPa]	N(actual)	N(estimated)	Abs e%
50	23	34	976.7	296.7049	296.3536	0.001186
50	23.1	33	976.4	295.5869	295.214	0.001263
50	22.9	33	976.2	295.2081	294.9139	0.000998

50	22.9	33	975.8	295.1908	294.809	0.001295
100	23.3	33	983.2	295.5097	297.2466	0.005843
100	23.3	33	982.8	295.4921	297.1419	0.005552
100	23	33	982.6	294.9246	296.715	0.006034
100	23.1	33	982.3	295.0977	296.7602	0.005602
150	23.6	28	984.5	288.7083	291.85	0.010765
150	23.8	28	984.3	289.0172	291.9926	0.01019
150	23.2	28	984	288.0565	291.34	0.01127
150	23.4	28	983.8	288.3654	291.4755	0.01067
200	23.7	28	992.1	288.4088	293.9347	0.0188
200	23.7	27	991.7	287.0439	292.5995	0.018987
200	23.3	28	991.5	287.7482	293.3977	0.019255
200	23.3	27	991.1	286.4071	292.0884	0.01945
200	23.2	27	990.9	286.2463	291.9496	0.019535
Maximum Absolute Percentage Error (%)						0.0195

In all, the results show that the model can be used to estimate the vertical profile of the radio refractivity in any climatic region.

VI. CONCLUSION

Development of an empirical multiple linear regression model for estimating the vertical profile of radio refractivity was presented. The model was developed based on the empirical meteorological data obtained in Cross River state, Nigeria. The model was validated with meteorological data obtained in Akure, in the South Western part of Nigeria. The simple multiple linear regression model will make it easier to simplify other equations that require the vertical profile of radio refractivity. It also reduces the computational complexity and hence makes it more efficient for automated applications.

REFERENCES

[1]. Mason, S. P. (2010). Atmospheric effects on radio frequency (RF) wave propagation in a humid, near-surface environment. Naval Postgraduate School Monterey Ca.

[2]. Bukata, R. P., Jerome, J. H., Kondratyev, A. S., &Pozdnyakov, D. V. (2018). Optical properties and remote sensing of inland and coastal waters. CRC press.

[3]. Simões, F., Hamelin, M., Grard, R., Aplin, K. L., Béghin, C., Berthelier, J. J., ...&Schwingenschuh, K. (2008). Electromagnetic wave propagation in the surface-ionosphere cavity of Venus. Journal of Geophysical Research: Planets, 113(E7).

[4]. Leyser, T. B., & Wong, A. Y. (2009). Powerful electromagnetic waves for active environmental research in geospace. Reviews of geophysics, 47(1).

[5]. Doose, L. R., Karkoschka, E., Tomasko, M. G., & Anderson, C. M. (2016). Vertical structure and optical properties of Titan's aerosols from radiance measurements made inside and outside the atmosphere. Icarus, 270, 355-375.

[6]. Pan, W., & Gardner, C. S. (2003). Seasonal variations of the atmospheric temperature structure at South Pole. Journal of Geophysical Research: Atmospheres, 108(D18).

[7]. Bernlöhr, K. (2000). Impact of atmospheric parameters on the atmospheric Cherenkov technique. Astroparticle Physics, 12(4), 255-268.

[8]. Nickolaenko, A. P., Galuk, Y. P., & Hayakawa, M. (2016). Vertical profile of atmospheric conductivity that matches Schumann resonance observations. SpringerPlus, 5(1), 108.

[9]. Kaspi, Y., & Showman, A. P. (2015). Atmospheric dynamics of terrestrial exoplanets over a wide range of orbital and atmospheric parameters. The Astrophysical Journal, 804(1), 60.

[10]. Körner, C. (2007). The use of 'altitude'in ecological research. Trends in ecology & evolution, 22(11), 569-574.

[11]. Guinn, T. A., & Barry, R. J. (2016). Quantifying the Effects of Humidity on Density Altitude Calculations for Professional Aviation Education. International Journal of Aviation, Aeronautics, and Aerospace, 3(3), 2.

[12]. Pierrehumbert, R. T., Brogniez, H., & Roca, R. (2007). On the relative humidity of the Earth's atmosphere. The General Circulation.

[13]. Kingsley, E. U., & Samuel, O. A. (2018). Review of Methodology to Obtain Parameters for Radio Wave Propagation at Low Altitudes from Meteorological Data: New Results for Auchi Area in Edo State, Nigeria. Journal of King Saud University-Science.

[14]. Du Castel, F. (2017). Tropospheric Radiowave Propagation Beyond the Horizon: International Series of Monographs in Electromagnetic Waves (Vol. 8). Elsevier.

[15]. Valtr, P., &Pechac, P. (2005). Tropospheric refraction modeling using ray-tracing and parabolic equation. RADIOENGINEERING-PRAGUE-, 14(4), 98.

[16]. Grabner, M., &Kvicera, V. (2011). Atmospheric refraction and propagation in lower troposphere. In Electromagnetic Waves. InTech.

[17]. Healy, S. B. (2001). Radio occultation bending angle and impact parameter errors caused by horizontal refractive index gradients in the troposphere: A simulation study. Journal of Geophysical Research: Atmospheres, 106(D11), 11875-11889.

[18]. Louf, V., Pujol, O., &Sauvageot, H. (2016). The Seasonal and Diurnal Cycles of Refractivity and Anomalous Propagation in the Sahelian Area from Microwave Radiometric Profiling. Journal of Atmospheric and Oceanic Technology, 33(10), 2095-2112.

[19]. Akinwumi, S. A., Omotosho, T. V., Willoughby, A. A., Mandeep, J. S., & Abdullah, M. (2015, August). Seasonal variation of surface radio refractivity and water vapour density for 48 stations in Nigeria. In Space Science and Communication (IconSpace), 2015 International Conference on (pp. 106-110). IEEE.

[20]. Agbo, G. A., Okoro, O. N., &Amechi, A. O. (2013). Atmospheric Refractivity over Abuja, Nigeria. International Research Journal of Pure and Applied Physics, 1(1), 37-45.

[21]. Otasowie, P. O., &Edeko, F. O. (2015). Radio Refractivity Study in Akure-Owo Digital Microwave Link in South Western Nigeria. Nigerian Journal of Technology, 34(3), 606-608.Adediji, A. T., &Ajewole, M. O. (2008). Vertical Profile of Radio Refractivity Gradient in Akure South-West Nigeria. Progress In Electromagnetics Research, 4, 157-168.