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Vertical Radio Refractivity Profile for Calabar in the Southern Region of Nigeria

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Abstract: In this paper, six months Radiosunde data for Calabar in the Southern region of Nigeria is used to model vertical refractivity profile. Calabar is located in Cross River State 4°57'North in latitude and 8°19'East in longitude which is in the South South region of the country. The Radiosunde data is obtained from Nigerian Meteorological Agency (NIMET). Particularly, cubic trendline model is developed for each of the six months to predict the vertical profile of refractivity in the lower atmosphere (< 150 m) above sea level). The model can be used to predict the refractivity at any height between 0 m and 150 m. Also, the model can enable the determination of point refractivity gradient which requires the refractivity at 0 m and at 65 m above sea level. Sample point refractivity gradient for the month of January. In the month of January, it was found that the point refractivity gradient is 124.278 N-units.

Keywords: Refractivity, Refractivity Gradient, Vertical Profile, Point Refractivity, Refractive Index

1. Introduction

Over the years, studies have shown that as radiowave propagates in the atmospheres and troposphere it is affected by many factors which include the variations of metrological parameters such as humidity, temperature and atmospheric pressure. These meteorological parameters, also called radio climatic parameters also determine the value of radio refractivity and refractivity index. Furthermore, studies show that multipath effects also occur as a result of large scale variations in atmospheric radio refractive index. Refractive index is defined as a ratio of the radio wave propagation velocity in free space to its velocity in a specified medium [1–7].

Apart from refractive index, another essential parameter in radio propagation studies is the vertical gradient of the refractive index [8-11]. The vertical gradient of the refractive index in the 1 km interval above ground are important for the estimation of super–refraction and ducting phenomena and their effects on radar observations and VHF field strength at points beyond the horizon [11]. Particularly, vertical gradient of the refractive index causes the bending of propagation direction of the radio waves [12]. If it is negative, the signal bends downward.

Accordingly, studies on vertical profiles of the refractive index has been presented in several studies in different parts of the globe [2, 11-16]. The main goals of this paper is to determine the variation of radio refractivity with height above ground for a location in Calabar in Cross River state based on Radiosunde meteorological data obtained in Calabar.

2 Methodology

2.1. Study Area

The study area for this work is Calabar in the South South of Nigeria. Calabar is located in Cross River State 4°57'North in latitude and 8°19' East in longitude. The southern part of Nigeria experiences heavy and abundant rainfall. The storms are usually conventional in nature due to the region's proximity to the equatorial belt. The annual rainfall received in this region is very high usually above the 2000mm (78.7in) rainfall totals giving for tropical rainforest climate worldwide.

2.2. Data

In this paper, Radiosunde data from Nigerian Meteorological Agency (NIMET) for Calabar is used. Six (6) months data for the year 2013 is used. The data contains the monthly data of temperature, pressure and relative humidity for various altitude above sea level for the first 6 months in the year 2013.

2.3. Spatial Interpolation

The interpolation method adopted for this work is the inverse distance weighting method [17-20]. This method is a deterministic method for multivariate interpolation with known scattered set of points. The assigned values to unknown points are calculated with weighted average of the values available at the known points. The name given to this type of method was motivated by the weighted average applied since it resort to the inverse of the distance to each known point (amount) of proximity when assigning weights. However, after the data was gathered, it was observed that the data lacked time and spatial resolution and therefore the need to interpolate. The Inverse distance weighting was applied on the data for three locations of Calabar, Lagos and Enugu used in this work. Approximations of virtually all spatial interpolation techniques can be denoted as weighted averages of sampled data and they all share the same general approximation method, as follows [17-20]:

$$Z'(\infty_{\circ}) = \sum_{i=0}^{R} \lambda_i \, Z(\infty_{\circ}) \quad (1)$$

Where Z` is the approximated value at the point of interest xo, Z is the known value at the sampled point i, λ_i is the weighting parameter and n denotes the number of sampled points used for approximation. The weighting bias can be represented by (2), where d_i is the distance between xo and xi, p is a power parameter, and n is as denoted previously [17-20]:

$$\lambda i = \frac{\frac{1}{(d_i)^p}}{\sum_{i=0}^{R} \frac{1}{(d_i)^p}} \quad (2)$$

2.4. Estimation of Refractivity

The ITU-R P.453-9 formula is used to compute the refractivity [21-24]:

$$N = \frac{77.6}{T} \left(P + 4810\frac{e}{T}\right) \quad (3)$$

where

T is the atmospheric temperature in kelvin

P (hpa) is the total atmospheric pressure

e (hpa) is the water vapour pressure

The water vapour pressure is given as [2, 21-24]:

$$e = \frac{6.112H}{100} \exp\left(\frac{17.5t}{t+240.9}\right) \quad (4)$$

where H is the relative humidity (Kelvin) is the atmospheric temperature

2.5. Refractivity Gradient

The atmospheric refractivity N (N-units) is given by [21-24]:

$$N = (n-1)*10^6 \quad (5)$$

The refractivity gradient is given as [21, 22, 23, 24]:

$$G = \frac{dN}{dh} \quad (6)$$

Also, G is given as [21, 22, 23, 24]

$$G = \frac{N2-N1}{h2-h1} \quad (7)$$

Where N2 is the refractivity at 65m

N1 is the refractivity at the ground level

h2 is the 65m altitude

h1 is the ground level

In essence, the refractivity gradient shows the relationship of how refractivity changes with height which is of greater interest to line of sight link design engineers.

3. Results and Discussion

3.1. The Six (6) Months Radiosunde Data for Calabar for the Year 2013

The Radiosunde data for Calabar for the months of January to June 2013 are presented in Table 1a to Table 1c. From the data in Table 1a to Table 1c it can be seen that generally, the temperature drops with height. Also, pressure drops with height. However, the relative humidity do not have such relationship with height.

Table 1a. *The Radiosunde Data For Calabar For The Months Of January and February 2013.*

JANUARY				**February**			
P[hPa]	**T[C]**	**H[%]**	**Altitude[m]**	**P[hPa]**	**T[C]**	**H[%]**	**Altitude[m]**
1013.1	31.5	66	0	1014.2	31.9	58	0
1006.7	30.3	84	44.3	1009	30.2	61	47.7
994.2	28.9	75.3	169.6	998.8	29.2	66.4	138.3
921.8	22.7	83.2	837.3	940.9	24.1	79.9	667.1
836.6	18.4	76.1	1683.9	854.5	21.5	30.4	1507.2
753.5	13.1	77.7	2575.8	777.8	15.5	35.6	2315.8
686.6	9.7	51.2	3355.4	710.1	10.1	39.3	3082.1
615.5	3.9	55	4259.4	647.8	6.7	56.1	3845.2
545.8	-2.5	37	5225.4	589.8	1.1	45.3	4609.8
489.9	-5.1	23.9	6081.9	534.8	-2.2	29.2	5396.6
440.9	-11.6	24.2	6902.6	482.8	-6.4	22.4	6207.5
393.2	-16.4	23.4	7777.6	436	-12.7	23	6998.6
351.7	-21.1	18.8	8612.8	392.4	-16.4	18.3	7799.7

JANUARY				February			
P[hPa]	**T[C]**	**H[%]**	**Altitude[m]**	**P[hPa]**	**T[C]**	**H[%]**	**Altitude[m]**
312.5	-29	22	9477.7	350.5	-22.1	16.1	8645
274.8	-37.7	35.4	10382.8	312.4	-29.9	15.8	9480.9
239.8	-45.4	32.7	11310.5	277.5	-37.7	16.4	10317.1
207.7	-51.7	22.8	12257.7	243.3	-45.6	16.7	11208.1
180.7	-59.4	26	13151.1	210.9	-52.2	16.6	12155.6
156.3	-66.1	22.2	14053.9	181.6	-60.2	16	13108.2
135.5	-72.7	23	14908.4	154.7	-68.8	14.9	14095.5
120.9	-76.1	25.1	15575.4	137.5	-73.7	15.1	14804.6

Table 1b. *The Radiosunde Data For Calabar For The Months Of March and April 2013.*

March				April			
P[hPa]	**T[C]**	**H[%]**	**Altitude[m]**	**P[hPa]**	**T[C]**	**H[%]**	**Altitude[m]**
1011.7	32.6	67	0	1013.9	26	98	0
1005.7	30.7	66.9	55.8	1008.7	27	94.5	25.4
994.2	29.2	69.9	154.9	998.3	26.7	86.4	136
923.9	23.2	84.9	806.1	933.7	25.9	59.7	727.8
845.3	18.4	88.4	1582.7	852.2	22.6	49.1	1532.9
766.5	17	45.5	2428.5	785.1	16.4	61.3	2245.9
691.9	9.9	63.1	3293.2	722.5	11.1	73.8	2948
625.8	3.7	76.3	4121.4	661.4	6.5	80.2	3681.6
562.8	0	62.5	4978.6	610.9	2	87.5	4331.1
501.3	-6.1	60.9	5899.2	564.8	-0.8	93.8	4965.5
445.1	-10.4	25.9	6826.4	535.4	-2.4	91.9	5395.7
394.5	-15	40.8	7752.5	507.8	-4.6	91.8	5815.1
348.6	-22.2	14.8	8677.4	478.9	-7.2	89.2	6274.4
305.6	-30.4	13.4	9635.6	449.2	-8.6	87.1	6778
268.1	-38.4	21.7	10556.2	421.6	-12.2	85.7	7266.7
232.9	-44.7	48.9	11514.2	383.5	-17.6	82.7	7988.9
202.7	-52.9	45.5	12430	348.8	-22	79.4	8690.2
175.1	-60.9	41.3	13362.4	318.8	-26.9	69.5	9355.5
149.6	-69.9	37.7	14327.1	288	-32.5	70.8	10082.4
125.3	-74.8	34.8	15377.7	263.2	-37.6	68.5	10715.7
111.9	-75.7	34.1	16032.2	242.3	-41.1	67.9	11283.4

Table 1c. *The Radiosunde Data For Calabar For The Months Of May and June 2013.*

May				June			
P[hPa]	**T[C]**	**H[%]**	**Altitude[m]**	**P[hPa]**	**T[C]**	**H[%]**	**Altitude[m]**
1014.8	32.2	67	0	1016.9	25.8	90	0
1009.6	30.9	84.7	49.3	1011.8	28.9	81.2	44.3
999.6	29.9	74.8	137.7	1001.8	24.9	82.3	133
934.5	24.2	82.3	734.6	935.8	21.1	85.3	729.8
830.5	17.2	88.9	1756.3	851.3	17.7	84.9	1549.4
699.8	9.8	89.5	3215.7	772.4	15.5	70	2382.1
620.2	1.6	84.3	4210	697.3	9.4	66.5	3243.5
553.4	-2.5	84.6	5126.6	629	3.2	78.4	4091.7
489	-7	75.1	6102.9	565.6	-0.9	79.7	4953.1
432.3	-11.9	67.2	7062.7	508.4	-5.5	78.5	5802
381.9	-17.5	75.1	8004.6	454.2	-9.3	66.9	6688.9
333.6	-23.4	55.7	9010.4	407.8	-14.3	59.7	7513.6
293	-30.7	40.5	9952.4	364	-20.1	49.2	8371.5
257.8	-38.2	41.1	10850.9	322	-26.3	65.9	9274.5
224.8	-46.4	37.7	11782.6	283.7	-32.1	62.1	10183.6
194.4	-54.5	37.7	12735.5	246.3	-39.6	56.7	11169.9
165.7	-63.4	39.9	13748.5	213.1	-47.8	51.3	12151.5
142.1	-69.9	39.1	14679.5	185	-56.7	47.5	13064.1
120.8	-77.6	36.9	15630.5	161.3	-63.1	40.1	13930.5
102.2	-79.7	39	16586.4	139.3	-69.3	38.5	14828
90.6	-82.1	33.9	17274.1	122.5	-75.5	37.8	15588.8

3.2. The Refractivity Profile

The refractivity profile for the months of January to June are given in Tables 2 and Figure 1.

Table 2. *Vertical Profile Of Refractivity in Calabar For The Month of January.*

Altitude[m]	DRY N	WET N	N	Altitude[m]	DRY N	WET N	N
0	0	8543.186	8543.186	7777.6	2036.241	476.1707	2512.411
379.8	85.13137	10725.07	10810.2	8203.8	2131.999	505.6543	2637.653
837.3	182.4101	14544.05	14726.46	8612.8	2290.45	331.2809	2621.731
1268.8	281.9556	10828.85	11110.81	9042.9	2402.359	317.6978	2720.057
1683.9	374.3072	10284.67	10658.98	9477.7	2493.117	350.9344	2844.051
2142.7	472.0997	10887.21	11359.31	9929.4	2562.426	444.9995	3007.425
2575.8	569.9518	9809.42	10379.37	10382.8	2612.533	614.2013	3226.735
2973.8	661.792	8709.949	9371.741	10833.7	2704.939	645.6168	3350.556
3355.4	803.1432	3164.098	3967.241	11310.5	2871.098	469.3247	3340.423
3772.4	875.4134	4594.783	5470.196	11796.2	2980.74	467.7199	3448.459
4259.4	1007.712	3333.483	4341.195	12257.7	3215.678	243.549	3459.227
4741.6	1153.443	2126.025	3279.467	12735.1	3330.784	237.5091	3568.294
5225.4	1308.036	1318.034	2626.07	13151.1	3413.128	251.1782	3664.306
5658.4	1398.827	1501.264	2900.091	13597	3573.069	192.0944	3765.163
6081.9	1589.611	609.3547	2198.965	14053.9	3694.386	177.4353	3871.821
6496.2	1709.99	516.3322	2226.322	14472	3795.293	171.8879	3967.181
6902.6	1802.294	557.2475	2359.541	14908.4	3908.418	160.6065	4069.025
7329.8	1939.947	424.4377	2364.385	15347.2	4009.908	157.1864	4167.095
7777.6	2036.241	476.1707	2512.411	15575.4	4054.515	160.2759	4214.791

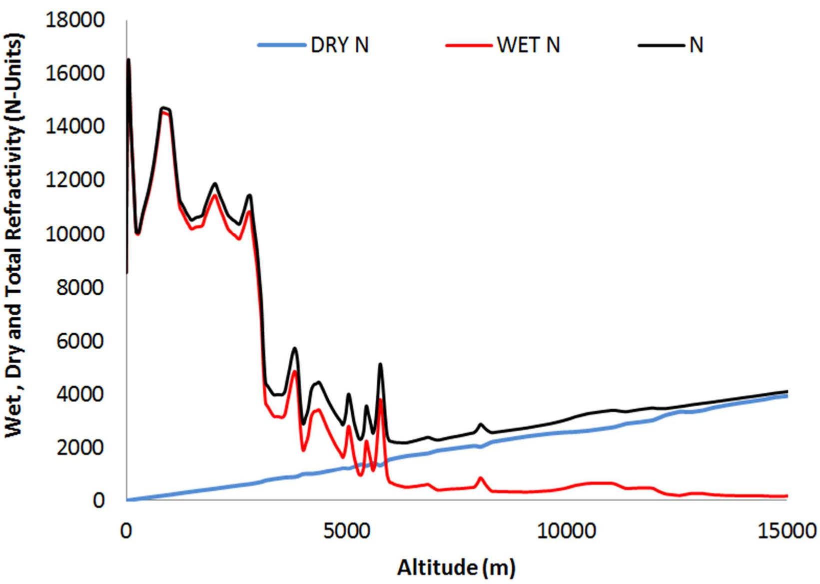

Figure 1. *Vertical Profile Of Refractivity in Calabar For The Month of January.*

From the data in Table 2, the vertical profile of refractivity for January in Calabar is given as;

$$N(h) = 0.0118(h^3) - 3.7778(h^2) + 319.98(h) + 8543.2 \quad (8)$$

Similarly, the vertical profile of refractivity for February in Calabar is given as;

$$N(h) = -0.0005(h^3) + 0.1094(h^2) + 12.355(h) + 6219.8 \quad (9)$$

The vertical profile of refractivity for March in Calabar is given as;

$$N(h) = -0.00001(h^3) + 0.0117(h^2) + 5.6735(h) + 8866.5 \quad (10)$$

The vertical profile of refractivity for May in Calabar is given as;

$$N(h) = 0.00003(h^3) + 0.0455(h^2) - 11.594(h) + 25936 \quad (11)$$

The vertical profile of refractivity for June in Calabar is given as;

$$N(h) = 0.000006(h^3) + 0.0026(h^2) - 5.6346(h) + 20152 \quad (12)$$

From the result in Table 2, it can be seen that the wet component of refractivity contributes the larger portion of the total refractivity. Also, the dry refractivity component increases linearly with height whereas the wet component of the refractivity do not have such linear relationship with height. The vertical refractivity profile for each of the six months is modeled using a cubic trendline model fitted to their graph.

From the vertical refractivity profile, the Point refractivity gradient can be computed. Point refractivity gradient is computed with refractivity at the height of 0m and 65m as follows:

$$dN1 = \frac{N(h2) - N(h1)}{h2 - h1} = \frac{N(65) - N(0)}{65 - 0}$$

For example, for the month of January, dN1 is given as;

$$N(h) = 0.0118(h^3) - 3.7778(h^2) + 319.98(h) + 8543.2$$

At 65 m above sea level, N(h) gives;

$$N(65) = 0.0118(65^3) - 3.7778(65^2) + 319.98(65) + 8543.2 = 16621.27$$

At 0 m above sea level, N(h) gives;

$$N(0) = 8866.548$$

$$dN1 = \frac{16621.27 - 8866.548}{65 - 0} = 124.278$$

4. Conclusion

The paper used six months Raduiosunde data for Calabar in the Southern region of Nigeria to model the vertical profile of refractivity. Particularly, cubic trendline model is developed for each of the months to predict the refractivity of the lower atmosphere (< 150 m above sea level). The model can be used to predict the refractivity at any height between 0 m and 150m. Also, the model can enable the determination of point refractivity gradient which requires the refractivity at 0 m and at 65 m above sea level. Sample Point Refractivity Gradient for the month of January was used to demonstrate one of the major applications of the vertical refractivity profile model. In the month of January, the point refractivity gradient is 124.278 N-units.

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