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DETERMINATION OF REFRACTIVITY GRADIENT AND MODIFIED REFRACTIVITY GRADIENT FOR CROSS RIVER STATE

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ABSTRACT

In this paper, determination of refractivity gradient and modified refractivity gradient for Cross River state was carried out. The year 2013 Radiosonde meteorological data from Nigerian Meteorological Agency (NIMET) was used. Refractivity, modified refractivity, refractivity gradient and modified refractivity gradient were computed. The results showed that in the year 2013, Cross River state had maximum modified refractivity gradient (dM/dz) of 114.9 (M -units/Km) and it occurred in December whereas the minimum modified refractivity gradient (dM/dz) on 81.9 (M–units/Km) and it occurred in October . Also, in the year 2013, the maximum refractivity gradient (dN/dz) was -42.1 (N-units/Km) and it occurred in December whereas the minimum refractivity gradient (dN/dz) was -75.1 (N-units/Km) and it occurred in October. The standard refractivity gradient of -39 N-units and standard modified refractivity gradient of 118 M-units occurred in December at altitude of 103 meters. In all the months the atmospheric condition was in the normal state except in the month of October where superrefraction occurred.

Contribution/Originality: This study is one of very few studies which have investigated the modified refractivity gradient for Cross River state. Available related studies on Cross River State were mainly on refractivity gradient.

1. INTRODUCTION

Studies on atmospheric parameters are very essential in the wireless industry as the parameters have great impact on radio waves as they propagate through the atmosphere. Especially, radio refractivity which is a function of temperature pressure and relative humidity determines the extent to which radio signal path can be bent as it propagates through the atmosphere (Gao *et al.*, 2008; Grabner *et al.*, 2012; Hurter and Maier, 2013; Akinwumi *et al.*, 2015; Series, 2015; Wang *et al.*, 2017). The value of radio refractivity varies with altitude and hence, the gradient of the radio refractivity in the atmosphere is also required in wireless network design.

Importantly, the refractivity gradient is used to determine the nature and degree of curvature of the radio signal path in the atmosphere. Under normal atmospheric conditions radio waves tend to bend downwards towards the earth whereas for subrefraction condition radio waves bend upwards away from the earth (Sim, 2002; Usman *et al.*, 2015; Bruin, 2016). In the case of superrefraction radio waves tend to bend downwards to the earth more than normal. Trapping occurs when the propagation path is bent downwards to such extent that it exceeds the

53

curvature of the earth (Sim, 2002; Branson, 2008; Bhattacharjea, 2014; Bruin, 2016; Manjula *et al.*, 2016). The visual representation of the different refractive conditions is given in Figure while the values of refractivity gradient and modified refractivity gradient for each of the different atmospheric conditions are listed in Table 1.
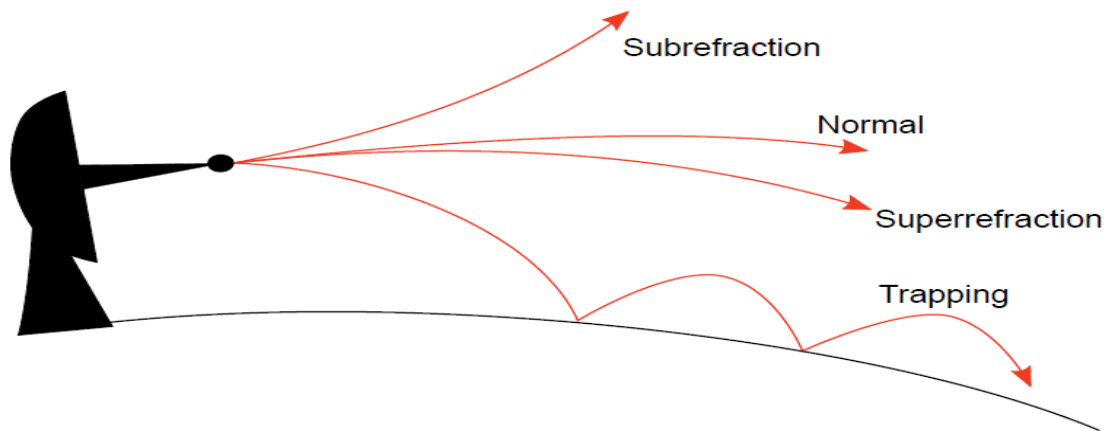

Figure-1. Visual representation of the different refractive conditions
Source: Bruin (2016) and Merrill (2008).

Table-1. Refractivity gradients and modified refractivity gradient under different conditions

Condition	N-gradient (N/Km)	M-gradient (M/Km)
Subrefraction	0<dN/dz	157<dM/dz
Normal	-79<dN/dz<0	79<dM/dz≤157
Standard	dN/dz = -79	dM/dz =118
Superrefraction	-157<dN/dz<-79	0<dM/dz≤79
Trapping	dN/dz <-157	dM/dz<0

Source: Bruin (2016) and Merrill (2008).

In this paper, the refractivity gradient and modified refractivity gradient for Cross River state in Nigeria are studied and the atmospheric conditions are identified based on the refractivity values for the various months in the year 2013. The study is based on the Radiosonde meteorological data from Nigerian Meteorological Agency (NIMET).

2. METHODOLOGY

Atmospheric radio refractivity consists of the wet (N_{wet}) and the dry (N_{dry}) components and the two components are determined from primary radioclimatic parameters, namely; temperature, pressure and relative humidity as follows (Agbo *et al.*, 2013; Akinwumi *et al.*, 2015; Louf *et al.*, 2016):

$$N = N_{dry} + N_{wet} = \frac{77.6}{T}\left(P + 4810\left(\frac{e}{T}\right)\right) \tag{1}$$

where absolute temperature, T is in Kelvin; the atmospheric pressure, p is in hPa and the water vapour pressure e is computed as follows:

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

Where the relative humidity, H is in % and the atmospheric temperature, t is in Celsius, Then, the modified refractivity, M is given as ;

$$M = N + \frac{z}{Re\,(10)^{-6}} = \frac{77.6}{T}\left(P + 4810\left(\frac{e}{T}\right)\right) + \frac{z}{Re\,(10)^{-6}} \approx N + 0.157(z) \tag{4}$$

Where

N is radio refractivity (dimensionless quantity in N-units).

M is Modified refractivity (dimensionless quantity in M-units).

z is Geometric height or the altitude (m)

Re is Radius of the earth (m).

Refractivity gradient, dN/dz is computed from the refractivity N_2 at altitude z_2 and refractivity N_1 at altitude z_1 as follows;

$$\frac{dN}{dz} = \frac{N_2 - N_1}{z_2 - z_1} \tag{5}$$

where

N , N_2 and N_1 are radio refractivity (dimensionless quantity in N-units).

z , z_2 and z_1 are Geometric height or the altitude (Km)

In most cases, z_1 is the surface level value , of 0 Km and N_1 is the surface refractivity denoted as N_s. In that case ,

$$\frac{dN}{dz} = \frac{N_2 - N_s}{z_2} \tag{6}$$

Similarly, modified refractivity gradient , dM/dz is computed from the refractivity M_2 at altitude z_2 and refractivity M_1 at altitude z_1 as follows;

$$\frac{dM}{dz} = \frac{M_2 - M_1}{z_2 - z_1} \tag{7}$$

where

M , M_2 and M_1 are radio refractivity (dimensionless quantity in M-units).

z , z_2 and z_1 are Geometric height or the altitude (Km)

In most cases, z_1 is the surface level value , of 0 Km and M_1 is the surface refractivity denoted as M_s. In that case ,

$$\frac{dM}{dz} = \frac{M_2 - M_s}{z_2} \tag{8}$$

3. RESULTS AND DISCUSSION

The vertical profile of the meteorological data for the month of January 2013 along with the computed refractivity, modified refractivity, refractivity gradient and modified refractivity gradient are given in Table 1. Similar tables for the months of October and December are given in Table 2 and Table 3 respectively.

Table-1. January 2013: The vertical profile of the meteorological data with the computed refractivity, modified refractivity, refractivity gradient and modified refractivity gradient

Altitude, z [m]	T [C]	U [%]	P [hPa]	N (N -Units)	M (M-Units)	dN/dz	dM/dz
0.00	30.60	64.87	1012.86	374.03	374.03	0.00	0.00
38.40	30.15	65.60	1008.65	372.01	378.03	-52.68	104.28
65.00	29.84	66.10	1005.73	370.60	380.80	-52.77	104.19
76.70	29.70	66.33	1004.44	369.98	382.02	-52.81	104.16
100.00	29.43	66.77	1001.89	368.74	384.44	-52.88	104.08
115.10	29.25	67.05	1000.23	367.88	385.95	-53.40	103.56
153.40	28.80	67.78	996.03	365.84	389.92	-53.39	103.58
191.80	28.35	68.51	991.81	363.78	393.89	-53.41	103.55
200.00	28.26	68.67	990.91	363.34	394.74	-53.42	103.54
230.10	27.91	69.24	987.61	361.73	397.84	-53.46	103.50
268.80	27.45	69.97	983.36	359.64	401.83	-53.52	103.44
300.00	27.09	70.57	979.94	357.96	405.05	-53.56	103.40
315.30	26.91	70.86	978.26	357.13	406.62	-53.59	103.37
371.00	26.26	71.92	972.15	354.12	412.35	-53.67	103.29
400.00	25.92	72.47	968.96	352.55	415.33	-53.71	103.25
422.30	25.66	72.89	966.52	351.34	417.62	-53.74	103.22
468.10	25.12	73.76	961.49	348.85	422.32	-53.79	103.17
500.00	24.75	74.37	957.99	347.11	425.60	-53.83	103.13
504.40	24.70	74.45	957.51	346.88	426.05	-53.83	103.13
541.80	24.26	75.16	953.40	344.84	429.88	-53.87	103.09
580.10	23.81	75.89	949.20	342.76	433.81	-53.90	103.06
620.80	23.34	76.66	944.73	340.55	437.99	-53.93	103.03
663.40	22.84	77.47	940.06	338.23	442.36	-53.96	103.00

Source: for T, U and P: NiMET (2013)

The graph of atmospheric temperature, pressure and relative humidity versus altitude for the month of January 2013 is given in Figure 1. Graph of refractivity and modified refractivity versus altitude for the month of January 2013 is given in Figure 2. Also, the graph of refractivity gradient and modified refractivity gradient versus altitude for the month of January 2013 are given in Figure 3. Table 1 and Figure 1 show that in January 2013 air temperature and pressure decrease with altitude whereas the relative humidity increases with altitude. This is in line with the generally observed pattern that air temperature and pressure decrease with altitude. However, , relative humidity does not generally decrease with altitude but varies depending on other atmospheric phenomena.
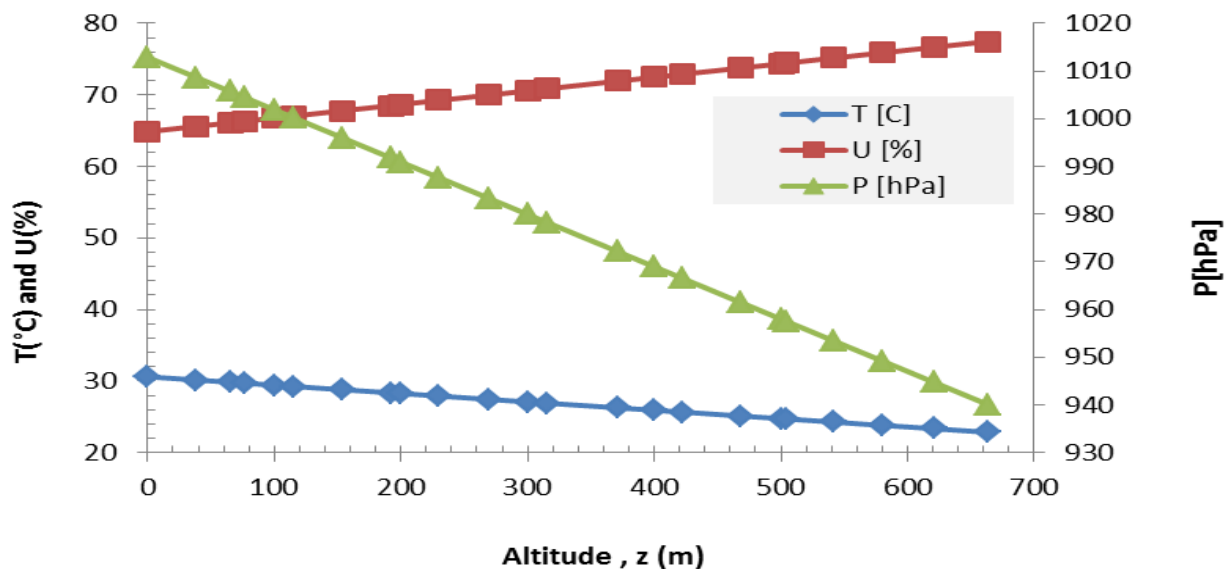

Figure-1. Graph of atmospheric Temperature, pressure and relative humidity versus altitude for the month of January 2013
Source: Generated by the authors using Mathlab program

Figure 2 shows that refractivity decreases with altitude as such in Figure 3 the refractivity gradient is negative. On the other hand, Figure 2 shows that modified refractivity increases with altitude and in Figure three, the modified refractivity gradient is positive.
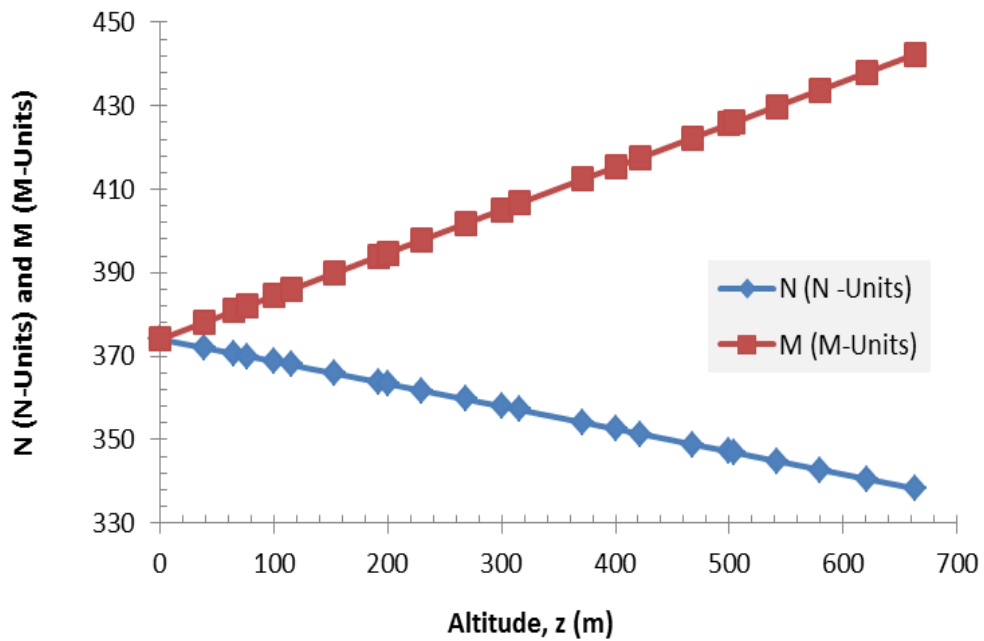

Figure-2. Graph of refractivity and modified refractivity versus altitude for the month of January 2013
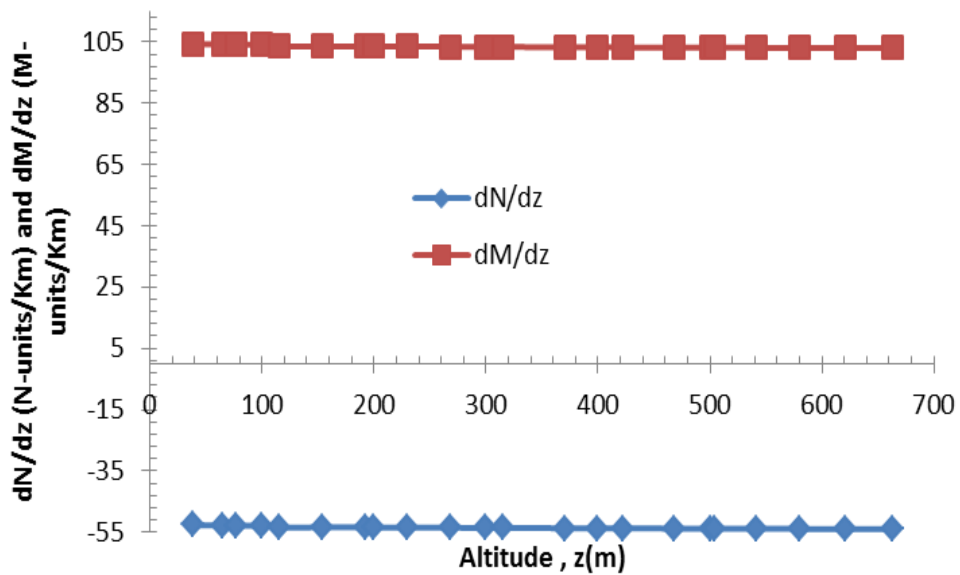**Source:** Generated by the authors using Mathlab program

Figure-3. Graph of refractivity gradient and modified refractivity gradient versus altitude for the month of January 2013
Source: Generated by the authors using Mathlab program

Table-2. October 2013: The vertical profile meteorological data with the computed refractivity, modified refractivity, refractivity gradient and modified refractivity gradient

Altitude[m]	T[C]	U[%]	P[hPa]	N (N -Units)	M	dN/dz	dM/dz
0.00	26.81	78.18	1015.96	377.19	377.19	0.00	0.00
14.80	26.57	78.49	1014.28	376.01	378.34	-79.41	77.56
29.60	26.34	78.81	1012.61	374.84	379.49	-79.30	77.66
44.50	26.10	79.13	1010.93	373.67	380.65	-79.20	77.76
59.30	25.86	79.45	1009.25	372.50	381.81	-79.09	77.87
65.00	25.77	79.58	1008.61	372.00	382.20	-79.81	77.15
74.10	25.62	79.77	1007.58	371.29	382.92	-79.64	77.32
88.90	25.38	80.09	1005.91	370.13	384.08	-79.42	77.54
100.00	25.20	80.33	1004.65	369.26	384.96	-79.27	77.69
103.70	25.14	80.41	1004.23	368.97	385.25	-79.23	77.74
118.60	24.90	80.73	1002.55	367.81	386.43	-79.05	77.91
133.40	24.67	81.05	1000.88	366.67	387.60	-78.89	78.07
148.20	24.43	81.37	999.20	365.52	388.78	-78.74	78.22
163.00	24.19	81.69	997.53	364.38	389.96	-78.60	78.36
177.80	23.95	82.01	995.86	363.24	391.15	-78.46	78.50
200.00	23.60	82.49	993.35	361.54	392.93	-78.25	78.71
226.80	23.17	83.06	990.32	359.50	395.10	-78.01	78.95
300.00	21.99	84.64	982.04	353.98	401.07	-77.37	79.59
337.00	21.39	85.44	977.86	351.23	404.12	-77.04	79.92
400.00	20.38	86.80	970.74	346.60	409.38	-76.48	80.48
447.10	19.62	87.81	965.41	343.18	413.36	-76.06	80.90
500.00	18.77	88.95	959.43	339.40	417.88	-75.58	81.38
557.30	17.85	90.19	952.95	335.36	422.83	-75.06	81.90

Source: Generated by the authors using Mathlab program

Table-3. December 2013: The vertical profile meteorological data with the computed refractivity, modified refractivity, refractivity gradient and modified refractivity gradient

Altitude[m]	T[C]	U[%]	P[hPa]	N (N -Units)	M	dN/dz	dM/dz
0.00	31.07	66.24	1012.81	378.87	378.87	0.00	0.00
54.10	30.56	67.42	1006.94	376.86	385.35	-37.29	119.68
65.00	30.46	67.66	1005.76	376.45	386.65	-37.37	119.59
100.00	30.13	68.42	1001.96	375.11	390.81	-37.64	119.32
108.20	30.05	68.60	1001.08	374.80	391.78	-37.70	119.26
162.30	29.55	69.78	995.21	372.63	398.11	-38.46	118.51
200.00	29.19	70.60	991.12	371.14	402.54	-38.65	118.31
216.40	29.04	70.96	989.34	370.49	404.46	-38.75	118.22
270.20	28.54	72.14	983.51	368.32	410.73	-39.06	117.90
300.00	28.26	72.79	980.28	367.10	414.19	-39.23	117.73
323.10	28.04	73.29	977.77	366.15	416.87	-39.37	117.59
375.20	27.55	74.43	972.12	363.99	422.88	-39.68	117.28
400.00	27.32	74.97	969.44	362.95	425.73	-39.82	117.14
427.90	27.06	75.58	966.41	361.77	428.93	-39.98	116.98
480.40	26.57	76.73	960.72	359.52	434.93	-40.28	116.68
500.00	26.39	77.16	958.59	358.68	437.16	-40.39	116.57
532.00	26.09	77.86	955.12	357.30	440.80	-40.56	116.40
582.40	25.61	78.96	949.66	355.10	446.51	-40.83	116.13
631.80	25.15	80.04	944.30	352.92	452.09	-41.08	115.88
682.00	24.68	81.13	938.86	350.68	457.73	-41.33	115.63
732.90	24.21	82.24	933.34	348.40	463.44	-41.58	115.38
785.30	23.71	83.39	927.66	346.03	469.29	-41.82	115.14
836.80	23.23	84.51	922.07	343.68	475.03	-42.05	114.91

Source: Generated by the authors using Mathlab program

The computed vertical profile of refractivity for the twelve months in 2013 are given in Table 4 and Figure 4. Similar table and figure for the modified refractivity are given in Table 5 and Figure 5. About 23 data points were used in the analysis for each of the months where the first data point 1 is the surface level data and the data point 23

is for the highest altitude. The altitudes for the different months are not the same, that is why data point serial number is used.

Table-4. The computed vertical profile of refractivity for the twelve months in 2013

S/N	N (N-Units) Jan	N (N-Units) Feb	N (N-Units) March	N (N-Units) Apr	N (N-Units) May	N (N-Units) Jun	N (N-Units) Jul	N (N-Units) Aug	N (N-Units) Sep	N (N-Units) Oct	N (N-Units) Nov	N (N-Units) Dec
1	374.0	370.8	384.0	384.6	362.9	376.9	387.1	378.5	380.0	377.2	382.6	378.9
2	372.0	367.5	381.7	381.2	360.2	374.3	383.8	375.6	376.6	376.0	379.9	376.9
3	370.6	366.2	380.9	380.7	359.2	373.5	383.2	374.8	375.4	374.8	379.3	376.4
4	370.0	363.8	379.4	378.6	357.5	371.7	381.1	373.0	372.9	373.7	377.5	375.1
5	368.7	363.3	379.2	377.9	357.2	371.6	380.4	372.8	373.1	372.5	377.1	374.8
6	367.9	359.0	377.0	374.6	354.8	369.0	377.2	370.2	369.7	372.0	374.3	372.6
7	365.8	357.0	374.7	372.7	352.2	366.5	375.0	367.5	366.4	371.3	372.4	371.1
8	363.8	354.8	374.4	371.2	351.6	366.3	374.1	367.2	365.8	370.1	371.5	370.5
9	363.3	351.1	372.4	368.0	349.6	364.0	371.1	365.1	363.2	369.3	368.8	368.3
10	361.7	350.4	370.2	366.8	346.1	361.3	369.2	362.5	360.2	369.0	367.3	367.1
11	359.6	347.4	369.6	364.9	344.4	361.1	368.0	361.6	359.0	367.8	366.1	366.2
12	358.0	343.9	368.1	361.7	341.8	358.7	364.9	359.8	357.2	366.7	363.5	364.0
13	357.1	343.8	364.9	361.0	340.6	356.0	363.3	357.0	354.2	365.5	362.2	362.9
14	354.1	340.0	366.0	358.2	339.3	355.9	361.4	356.1	352.4	364.4	360.8	361.8
15	352.5	337.6	363.9	355.2	336.7	353.2	357.8	354.3	351.0	363.2	358.1	359.5
16	351.3	336.2	361.7	354.5	335.2	350.7	357.6	351.6	345.9	361.5	357.2	358.7
17	348.8	332.5	360.2	351.0	334.5	350.3	354.1	350.6	348.0	359.5	355.5	357.3
18	347.1	329.0	359.4	347.7	332.1	347.7	350.1	348.7	345.0	354.0	353.0	355.1
19	346.9	325.6	357.2	344.2	327.5	345.0	346.0	345.6	342.1	351.2	350.5	352.9
20	344.8	322.3	355.0	341.3	325.3	342.5	341.6	342.6	339.3	346.6	348.0	350.7
21	342.8	318.9	352.6	338.5	323.2	339.8	337.3	339.4	336.5	343.2	345.4	348.4
22	340.5	315.6	350.2	335.9	320.9	337.2	333.0	336.1	333.7	339.4	342.8	346.0
23	338.2	312.5	347.7	333.2	318.6	334.5	329.0	333.0	331.0	335.4	340.3	343.7

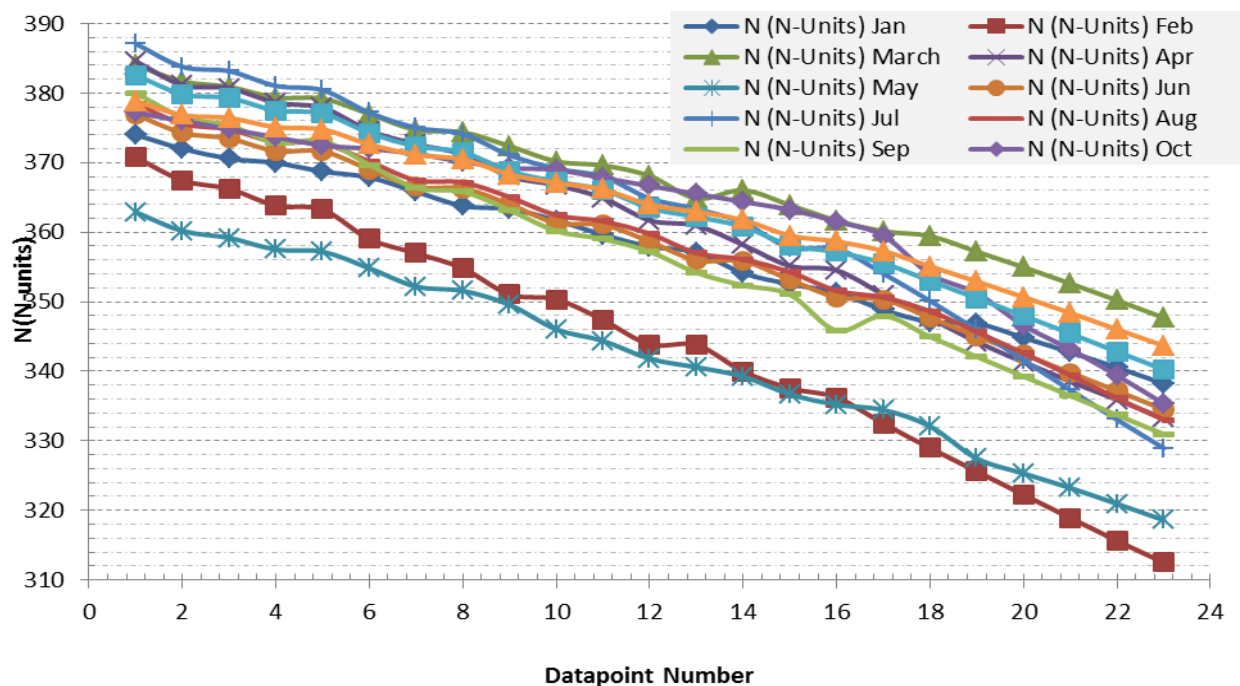**Source:** Generated by the authors using Mathlab program

Figure-4. The computed vertical profile of refractivity for the twelve months in 2013
Source: Generated by the authors using Mathlab program

From Table 4 and Figure 4 , the month of May has the lowest refractivity of 362.9(N-units). whereas April has the highest surface level refractivity value of 384.6 (N-units). Similar modified refractivity values are obtained from Table 5 and Figure 5.

59

Table-5. The computed vertical profile of modified refractivity for the twelve months in 2013

M (M-Units) Jan	M (M-Units) Feb	M (M-Units) March	M (M-Units) Apr	M (M-Units) May	M (M-Units) Jun	M (M-Units) Jul	M (M-Units) Aug	M (M-Units) Sep	M (M-Units) Oct	M (M-Units) Nov	M (M-Units) Dec
374.0	370.8	384.0	384.6	362.9	376.9	387.1	378.5	380.0	377.2	382.6	378.9
378.0	374.9	389.3	390.2	367.6	382.1	392.4	383.5	384.1	378.3	388.3	385.3
380.8	376.5	391.1	390.9	369.4	383.7	393.4	385.0	385.6	379.5	389.5	386.6
382.0	379.5	394.5	394.3	372.3	387.2	396.8	388.3	388.6	380.7	393.2	390.8
384.4	380.3	394.9	395.5	372.9	387.3	397.8	388.5	388.3	381.8	394.1	391.8
385.9	385.7	399.8	400.8	377.1	392.3	402.9	393.1	392.4	382.2	399.8	398.1
389.9	388.4	405.0	404.0	381.8	397.4	406.4	398.0	396.6	382.9	403.8	402.5
393.9	391.3	405.8	406.4	383.0	397.7	407.9	398.6	397.2	384.1	405.5	404.5
394.7	396.5	410.3	411.8	386.6	402.3	413.0	402.4	400.7	385.0	411.2	410.7
397.8	397.4	415.4	413.9	393.1	407.6	416.2	407.1	404.6	385.3	414.4	414.2
401.8	401.6	416.7	417.0	396.2	408.2	418.2	408.7	406.1	386.4	416.8	416.9
405.0	406.7	420.2	422.4	401.1	413.0	423.5	412.0	408.5	387.6	422.4	422.9
406.6	406.8	427.7	423.7	403.4	418.4	426.1	417.2	412.6	388.8	425.0	425.7
412.4	412.4	425.0	428.5	405.9	418.6	429.5	418.9	415.2	390.0	428.0	428.9
415.3	416.0	429.9	433.6	410.8	424.0	435.8	422.3	417.0	391.1	433.6	434.9
417.6	418.0	435.1	434.8	413.7	429.1	436.1	427.4	424.3	392.9	435.6	437.2
422.3	423.8	438.6	440.8	415.1	429.8	442.4	429.1	421.3	395.1	439.0	440.8
425.6	429.4	440.3	446.7	419.7	435.2	449.5	432.9	425.7	401.1	444.4	446.5
426.0	434.8	445.5	452.8	428.8	440.6	457.1	438.7	429.8	404.1	449.7	452.1
429.9	440.3	450.8	458.0	433.1	445.9	465.1	444.5	434.0	409.4	455.0	457.7
433.8	445.9	456.3	463.0	437.3	451.4	473.2	450.7	438.2	413.4	460.5	463.4
438.0	451.6	462.0	467.7	441.9	456.9	481.4	457.2	442.5	417.9	466.1	469.3
442.4	457.0	468.0	472.6	446.7	462.4	489.3	463.4	446.8	422.8	471.6	475.0

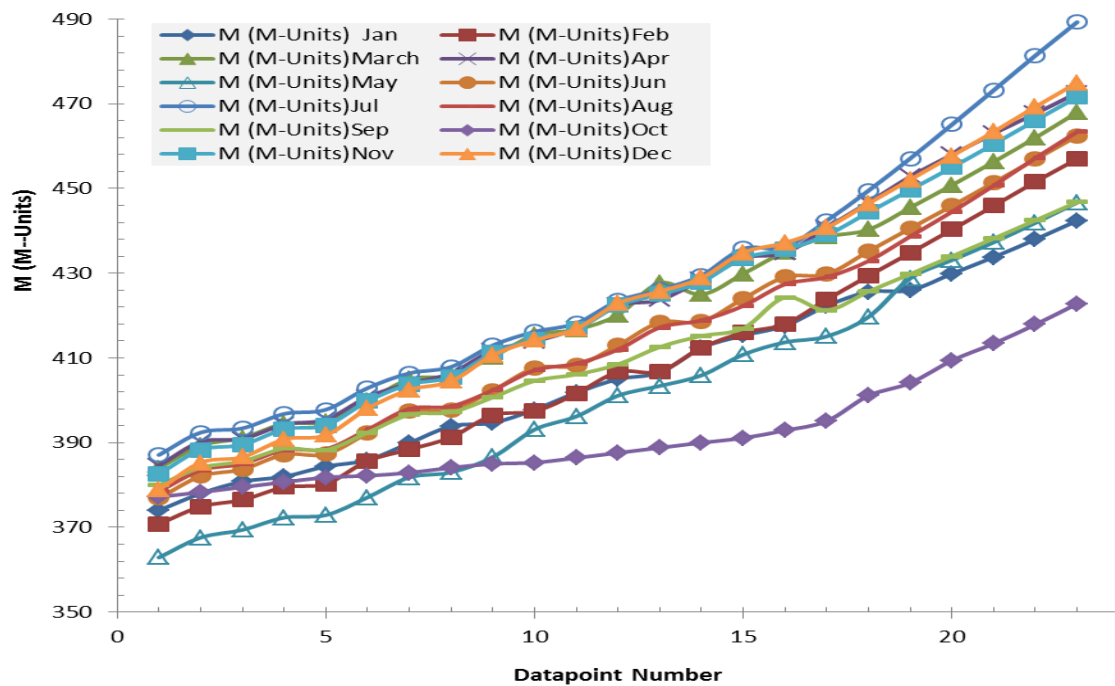**Source:** Generated by the authors using Mathlab program

Figure-5. The computed vertical profile of modified refractivity for the twelve months in 2013
Source: Generated by the authors using Mathlab program

The computed vertical profile of refractivity gradient for the twelve months in 2013 are given in Table 6 and Figure 6. Similar table and figure for the modified refractivity gradient are given in Table 7 and Figure 7. From the results in Table 6 and Figure 6, he maximum refractivity gradient (dN/dz) = -42.1and it occurred in December whereas the minimum refractivity gradient (dN/dz) = -75.1 and it occurred in October. Also, From the results in Table 7 and Figure 7, in the year 2013, the maximum modified refractivity gradient (dM/dz) = 114.9 and it

60

occurred in December whereas the minimum modified refractivity gradient (dM/dz) = 81.9 and it occurred in October.

Table-6. The computed vertical profile of refractivity gradient for the twelve months in 2013

dM/dz Jan	dM/dz Feb	dM/dz March	dM/dz Apr	dM/dz May	dM/dz Jun	dM/dz Jul	dM/dz Aug	dM/dz Sep	dM/dz Oct	dM/dz Nov	dM/dz Dec
104.3	86.9	108.7	97.3	100.1	104.0	96.2	100.2	84.9	77.6	105.9	119.7
104.2	87.0	108.8	97.3	100.2	104.0	96.3	100.2	85.1	77.7	105.9	119.6
104.2	87.3	108.8	97.4	100.3	104.0	96.4	100.3	85.4	77.8	105.9	119.3
104.1	87.4	108.8	97.4	100.3	104.0	96.5	100.3	85.3	77.9	105.9	119.3
103.6	87.6	108.5	97.1	100.1	103.7	96.4	100.1	85.4	77.2	105.6	118.5
103.6	87.9	108.7	97.3	100.4	103.9	96.6	100.3	85.9	77.3	105.7	118.3
103.5	88.2	108.7	97.4	100.4	103.9	96.7	100.3	86.0	77.5	105.7	118.2
103.5	88.7	108.8	97.5	100.6	104.0	96.9	100.5	86.4	77.7	105.8	117.9
103.5	88.8	108.9	97.6	100.9	104.1	97.1	100.6	86.8	77.7	105.9	117.7
103.4	89.2	108.9	97.7	101.0	104.1	97.2	100.7	86.9	77.9	105.9	117.6
103.4	89.7	108.9	97.8	101.2	104.2	97.4	100.8	87.2	78.1	105.9	117.3
103.4	89.7	109.0	97.9	101.3	104.3	97.5	100.9	87.6	78.2	106.0	117.1
103.3	90.2	109.0	98.0	101.4	104.3	97.7	101.0	87.8	78.4	106.0	117.0
103.3	90.5	109.1	98.1	101.5	104.3	98.0	101.1	88.0	78.5	106.0	116.7
103.2	90.7	109.1	98.1	101.6	104.4	98.0	101.2	88.6	78.7	106.0	116.6
103.2	91.1	109.2	98.3	101.7	104.4	98.2	101.3	88.3	78.9	106.1	116.4
103.1	91.6	109.2	98.4	101.8	104.5	98.5	101.4	88.7	79.6	106.1	116.1
103.1	92.0	109.3	98.6	102.1	104.6	98.8	101.6	89.1	79.9	106.2	115.9
103.1	92.4	109.3	98.7	102.3	104.7	99.1	101.7	89.4	80.5	106.2	115.6
103.1	92.9	109.4	98.9	102.4	104.7	99.4	101.9	89.8	80.9	106.2	115.4
103.0	93.3	109.5	99.0	102.6	104.8	99.7	102.1	90.1	81.4	106.3	115.1
103.0	93.7	109.5	99.1	102.7	104.9	100.0	102.2	90.5	81.9	106.3	114.9

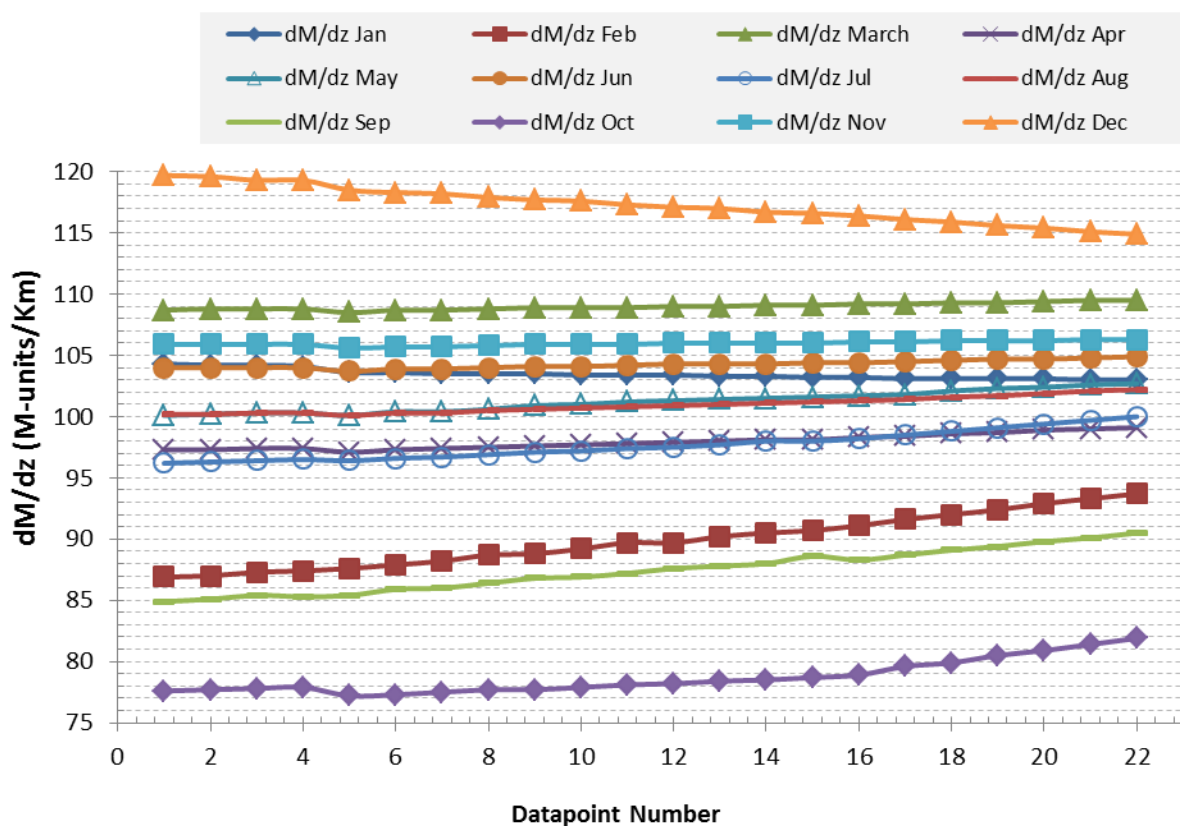**Source:** Generated by the authors using Mathlab program

Figure-6. The computed vertical profile of refractivity gradient for the twelve months in 2013
Source: Generated by the authors using Mathlab program

Table-7. The computed vertical profile of modified refractivity gradient for the twelve months in 2013

dN/dz Jan	dN/dz Feb	dN/dz March	dN/dz Apr	dN/dz May	dN/dz Jun	dN/dz Jul	dN/dz Aug	dN/dz Sep	dN/dz Oct	dN/dz Nov	dN/dz Dec
−52.7	−70.1	−48.2	−59.7	−56.8	−53.0	−60.7	−56.8	−72.0	−79.4	−51.0	−37.3
−52.8	−69.9	−48.2	−59.6	−56.8	−53.0	−60.7	−56.8	−71.9	−79.3	−51.0	−37.4
−52.8	−69.7	−48.2	−59.6	−56.7	−52.9	−60.6	−56.7	−71.6	−79.2	−51.0	−37.6
−52.9	−69.6	−48.2	−59.6	−56.6	−52.9	−60.5	−56.7	−71.6	−79.1	−51.0	−37.7
−53.4	−69.3	−48.5	−59.8	−56.8	−53.2	−60.6	−56.9	−71.5	−79.8	−51.3	−38.5
−53.4	−69.0	−48.3	−59.7	−56.6	−53.1	−60.4	−56.7	−71.0	−79.6	−51.2	−38.7
−53.4	−68.7	−48.3	−59.6	−56.5	−53.1	−60.3	−56.6	−71.0	−79.4	−51.2	−38.7
−53.4	−68.2	−48.2	−59.4	−56.4	−53.0	−60.0	−56.5	−70.6	−79.3	−51.1	−39.1
−53.5	−68.1	−48.1	−59.4	−56.1	−52.9	−59.9	−56.3	−70.2	−79.2	−51.1	−39.2
−53.5	−67.7	−48.1	−59.3	−56.0	−52.9	−59.8	−56.3	−70.0	−79.1	−51.1	−39.4
−53.6	−67.3	−48.0	−59.1	−55.8	−52.8	−59.5	−56.2	−69.8	−78.9	−51.0	−39.7
−53.6	−67.3	−47.9	−59.1	−55.7	−52.7	−59.4	−56.0	−69.4	−78.7	−51.0	−39.8
−53.7	−66.8	−48.0	−59.0	−55.6	−52.7	−59.3	−56.0	−69.2	−78.6	−51.0	−40.0
−53.7	−66.5	−47.9	−58.9	−55.4	−52.6	−59.0	−55.9	−69.0	−78.5	−50.9	−40.3
−53.7	−66.3	−47.8	−58.8	−55.3	−52.5	−59.0	−55.7	−68.3	−78.3	−50.9	−40.4
−53.8	−65.8	−47.8	−58.7	−55.3	−52.5	−58.7	−55.7	−68.6	−78.0	−50.9	−40.6
−53.8	−65.4	−47.7	−58.5	−55.1	−52.5	−58.4	−55.6	−68.2	−77.4	−50.8	−40.8
−53.8	−65.0	−47.7	−58.4	−54.8	−52.4	−58.1	−55.4	−67.9	−77.0	−50.8	−41.1
−53.9	−64.5	−47.6	−58.2	−54.7	−52.3	−57.8	−55.3	−67.5	−76.5	−50.8	−41.3
−53.9	−64.1	−47.6	−58.1	−54.6	−52.2	−57.5	−55.1	−67.2	−76.1	−50.7	−41.6
−53.9	−63.7	−47.5	−58.0	−54.4	−52.1	−57.2	−54.9	−66.8	−75.6	−50.7	−41.8
−54.0	−63.3	−47.4	−57.8	−54.3	−52.1	−56.9	−54.7	−66.5	−75.1	−50.6	−42.1

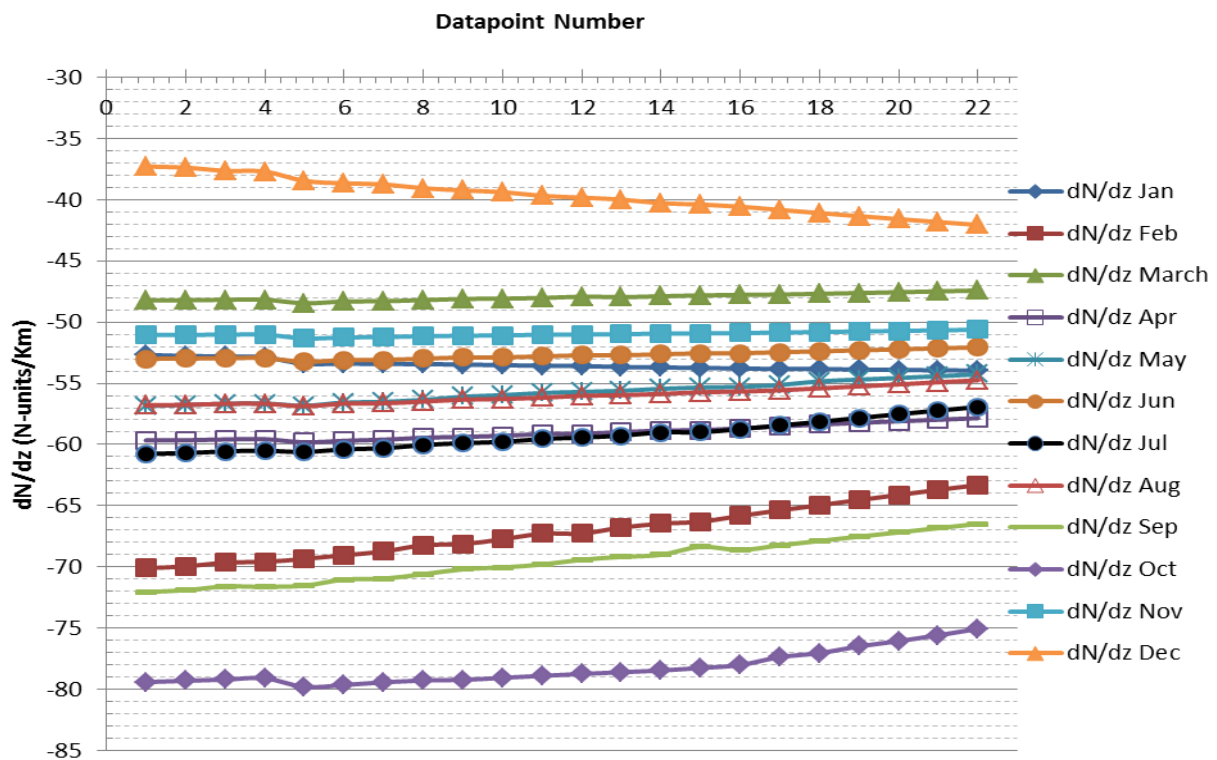**Source:** Generated by the authors using Mathlab program

Figure-7. The computed vertical profile of modified refractivity gradient for the twelve months in 2013
Source: Generated by the authors using Mathlab program

In all, from the results in Table 6 and Table 7, the standard refractivity gradient of −39 and standard modified refractivity gradient of 118 occurred in December at an altitude of 103 meters. In all the months the atmospheric condition was in the normal state except in the month of October where superrefraction occurred.

4. CONCLUSION

A study of the refractivity gradient and modified refractivity gradient for Cross River state was presented. Radiosonde meteorological data from Nigerian Meteorological Agency (NIMET) for the year 2013 was used. The vertical profile of each of the following four parameters was computed for the twelve months; refractivity, modified refractivity, refractivity gradient and modified refractivity gradient. The result showed that Cross River state is generally in the normal atmospheric condition except for the month of October where superrefraction was observed.

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