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Diurnal Variation of Surface Radio Refractivity Over Three Meteorological Stations in Nigeria

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***Abstract*— Analysis and study of the vertical variation of refractivity in the troposphere is required for radio systems planning in order to achieve successful operation. The diurnal variation of surface radio refractivity over three meteorological stations in Nigeria is presented. The stations include Lagos-Ikeja ($6^0$35'N, $3^0$40'E), Akure ($7^0$15'09"N, $5^0$11'35"E) and Minna ($9^0$37'N, $6^0$32'E). Monthly mean values of temperature, pressure and relative humidity were used to compute refractivity for three stations. The surface refractivity also shows latitudinal and seasonal variation. The maximum refractivity values were obtained for Ikeja (Lagos) of 394 N-units, Akure of 404 N-units and Minna of 364 N-units.**

Keywords*— *Refractivity, Refractive Index, radio wave propagation

I. Introduction

The atmosphere is the gaseous region surrounding the earth and it contains gases and water vapour. It is a mixture of about 78% Nitrogen, 21% Oxygen and 1% of other gases and contains water vapor, which varies in amount from 0 to 5 percent or more by volume.

The earth is divided into distinct layers, troposphere, stratosphere, mesosphere, thermosphere, ionosphere and exosphere. The troposphere is the lowest layer of the atmosphere extending to about 8 to 14.4 kilometers high. This part is the most dense. Almost all types of weather are in this region. The stratosphere starts just above the troposphere and extends to 50 kilometers high. The ozone layer, which absorbs and scatters the solar ultraviolet radiation, is in this layer. The mesosphere starts just above the stratosphere and extends to 85 kilometers high. The thermosphere starts just above the mesosphere and extends to 600 kilometers high. The ionosphere is an abundant layer of electrons and ionized atoms and molecules that stretches from about 48 kilometers above the surface to the edge of space at about 965 kilometers, overlapping into the mesosphere and thermosphere. The exosphere is the upper limit of our atmosphere. It extends from the top of the thermosphere up to 10,000 kilometers.

Radio waves are electromagnetic radiations that travel through space. They are due to interactions between the oscillating electric and magnetic fields. Radio waves, like every other member in the electromagnetic spectrum, travel with the same velocity known as the speed of light which is about 3×10^8 m/s. If the electromagnetic wave travels through any constitutive media, this velocity will be modified. Radio waves are transmitted into the atmosphere from television and radio broadcast stations. The velocity and direction of radio waves changes when it moves through different layers of the atmosphere. This is due to variation in the density of the atmosphere.

The ratio of the velocity of radio waves in vacuum to the velocity in a medium is the refractive index of the medium. The ratio determines the change in velocity and direction of the radio waves and depends on several atmospheric parameters. A radio wave propagated close to the earth's surface and partially following the curvature of the earth is called ground wave or surface wave. A radio wave propagation in a straight line is known as direct wave. Direct wave and ground (surface) wave constitute the space wave. Space waves are radio waves which travel through the earth's troposphere. Space wave propagation makes communication possible at frequencies above 30 MHz.

Analysis and study of the vertical variation of refractivity in the troposphere is required for radio systems. The gradual variations in the refractive index result in the bending of the paths taken by radio waves (a phenomena known as refraction) so that they can follow the curvature of the earth. Thus the troposphere affects the propagation of ground waves and can promote radio communication over large ranges. Radio waves are transmitted into the atmosphere from television and radio broadcasting stations. The velocity of radio waves in vacuum to the velocity in a medium is the refractive index of the medium. Radio waves travel through straight lines in a medium with constant refractive index. The refractive index of the atmosphere is the major parameter in the study of radio wave propagation which causes refraction of radio waves. As a result of high wave refractivity scattering, absorption, fragmentation and power loss occurred in the system which considerably affects the fidelity of the received signal.

The problem of refractivity is very important for predicting the quality of radio wave propagation, transmission and reception in the system. Hence, the need to determine the factors affecting the transmission and reception of radio signals would lead to improvement in the reception of local signal around us which necessitated this field of research.

The radio waves which radiate away from transmitting antennas travel most easily in dry air, and in paths that are close to a straight line. Even in dry air, they do gradually become weaker with distance, because of the way they are steadily spreading out as they radiate away. Refractivity has great impact on the transmitted radio signals which affects the signal power that could be received at the receiver end. Through this work, it was established that transmitter efficiency is higher in regions of low refractivity. Hence, knowing the refractivity gives an idea of signal power loss.

Variations of temperature, pressure and humidity, as well as clouds and rains, influence the way in which radio waves propagate from one location to another in the troposphere. The refractive index of troposphere plays a central role in the propagation of radio waves at high frequencies [1]. The troposphere is a very important part of the earth's atmosphere for the propagation of radio waves in the frequency range from 100-1000MHz, that is, very high frequency. This range of frequency is used principally for television broadcasting, terrestrial microwave telecommunication services, satellite communication and radar systems. Ionization of the air in the troposphere is negligible since ultra-violet radiation reaching troposphere is negligibly small, but due to the presence of gases like oxygen and water vapor, which have electric dipole moments, the troposphere has dielectric constant and hence a refractive index [2].

In fact, electromagnetic wave transmitted at an oblique angle undergoes a progressive refraction, curving downwards as a result of variations in pressure and temperature with altitude and effects due to water vapour, all of which decrease with increasing altitude in the troposphere.

The effect of meteorological variables of pressure, temperature and relative humidity on radio wave propagation at ultra-high frequency and microwave frequencies are analyzed from the study of radio refractive index derived from pressure, temperature and relative humidity [3]. As these variable parameters vary considerably diurnally and seasonally, especially in the tropics, quantitative knowledge of refractivity variations is needed in order to be able to design reliable and efficient radio communication systems.

II. RADIO REFRACTIVE INDEX AND REFRACTIVITY

The ratio of the velocity of radio waves in vacuum to the velocity in a medium is the refractive index of the medium. Refractive index variations of the atmosphere affect radio frequencies. The radio refractive index (n) of the troposphere deviates from unity as a result of polarisability of the constituent molecules. As molecular polarisability is independent of frequency also the molecular resonance is frequency dependent, and (n) tends to be dispersive [4].

Radio refractivity N is a measure of deviation of refractive index n of air and is a dimensionless quantity measured in N units [5].

$$N = (n - 1) \times 10^6 \qquad (1)$$

N depends on meteorological parameters of pressure *P* (hPa), temperature *T*(K) and water vapour pressure *e* (hPa), in accordance to [5].

$$N = \frac{77.6P}{T} + 3.73 \times 10^5 \frac{e}{T^2} \qquad (2)$$

The vapour pressure is related to the relative humidity *H* (%) [5].

$$e = \frac{He_s}{100} \qquad (3)$$

Where e_s is the maximum vapour pressure at any given air temperature $t\,^0C$, and may be calculated from:

$$e_s = 6.11 \exp\left[\frac{17.502t}{t+240.97}\right] \qquad (4)$$

Where e_s is saturated vapour pressure in mbar.

According to [5], P and e decrease rapidly with height while T decreases with height.

The change in refractive index with height influences radio waves to curve downwards. Surface radio refractivity N_s is known to have high correlation with radio field strength values according to [1].

Furthermore while the surface refractivity gradient depends on N_s determines the refractivity condition of the atmosphere may result in a normal, sub-refractive, super-refractive or ducting layer, each of which has important influences on propagation of signals and microwaves in the atmosphere. Under normal atmospheric conditions the refractive index of air decreases uniformly with height and the surface value N_s is known to have a good positive correlation with ΔN representing the refractivity gradient in the first 1 kilometre above the surface [6].

Generally, N_s is commonly used due to the relative ease in obtaining the relative surface parameters of temperature, pressure and relative humidity from different stations.

Reasonably, the use of N_s, diurnal and seasonal variability is useful in planning radio links in the troposphere. The work of [7] and others focus on climate, altitude and vegetation impact on surface refractivity.

III. METHODOLOGY

The data used were obtained from the Nigerian Meteorological Agency Department (NIMET), Lagos. Pressure, temperature and relative humidity data for the year 2010 to 2013 were collected for three meteorological stations in Nigeria. These stations include Lagos-Ikeja ($6^0$35'N, $3^0$40'E), Akure ($7^0$15'09"N, $5^0$11'35"E) and Minna ($9^0$37'N, $6^0$32'E).

Monthly values of pressure, temperature and water vapour were used to compute monthly values of refractivity. The temperature values were converted from Celsius (^{0}C) to Kelvin (K) while the relative humidity values were used to compute the saturation vapour pressure which is in turn used to compute the water vapour pressure using equations 2, 3 and 4. The refractivity values calculated for January 2010 for Lagos (Ikeja) is shown in Table 1 and the computed refractivity values for the three stations in Table 2.

IV. RESULTS AND DISCUSSION

The refractivity values calculated for the month of January 2010 in Lagos (Ikeja) is shown in Table 1., which show that refractivity values vary daily. The diurnal variations are influenced by three atmospheric parameters: pressure, temperature and water vapour pressure. Of the three atmospheric parameters, water vapour pressure has the greater effect on refractivity variations followed by temperature.

The high values of the water vapour pressure in the morning and evening periods give rise to the higher values of refractivity. These different meteorological parameters can work together to produce different refractivity conditions. It is also noticed that the refractivity has latitudinal variations as shown in Table 1. The following maximum values were obtained for Ikeja (Lagos) of 394 N-units, Akure of 404 N-units and Minna of 364 N-units. These variations are due to the fact that water vapour values which is the most important atmospheric parameter, that determines refractivity in all the

three stations are observed to be generally high during the wet season (April – September). The variations of surface refractivity for the rainy season and dry season are shown for Lagos (Ikeja) in Fig.1 and 2, for Akure in Fig. 3 and 4 and for Minna in Fig. 5 and 6. The Latitudinal variation of Refractivity over Lagos, Akure and Minna is shown in Fig. 7, while the seasonal variation of refractivity over Lagos, Akure and Minna is shown in Fig. 8.

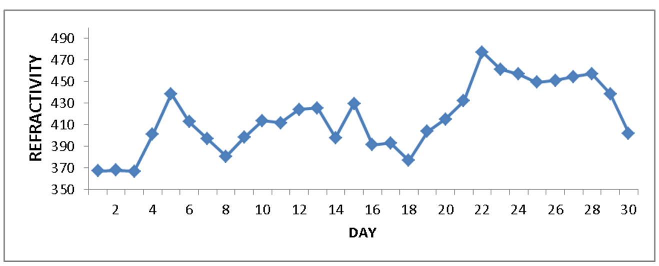

Fig. 1. Variation of surface refractivity over Lagos for rainy season.

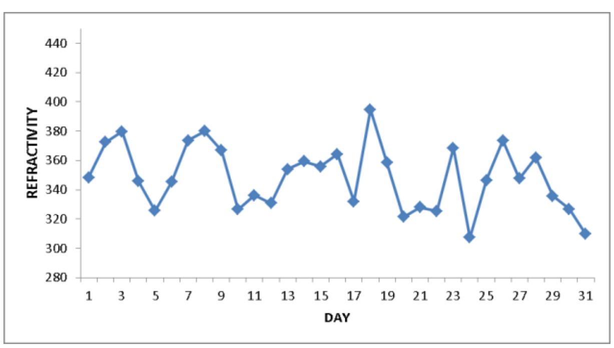

Fig. 2. Variation of surface refractivity over Lagos for dry season.

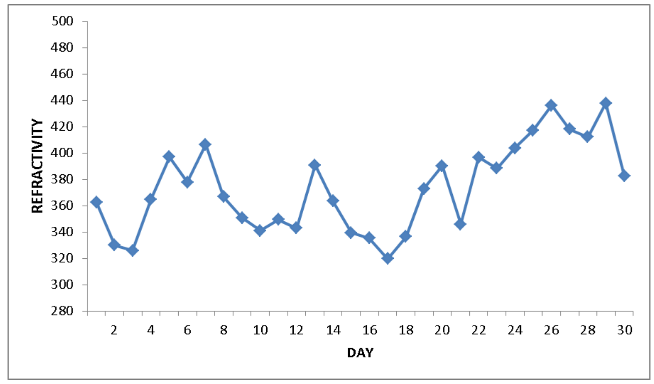

Fig. 3. Variation of surface refractivity over Akure for rainy season.

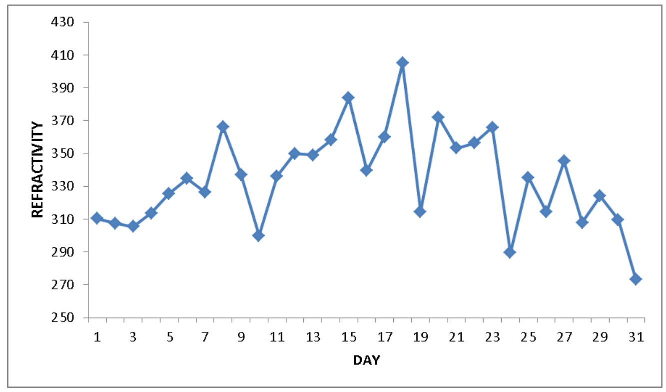

Fig. 4. Variation of surface refractivity over Akure for dry season..

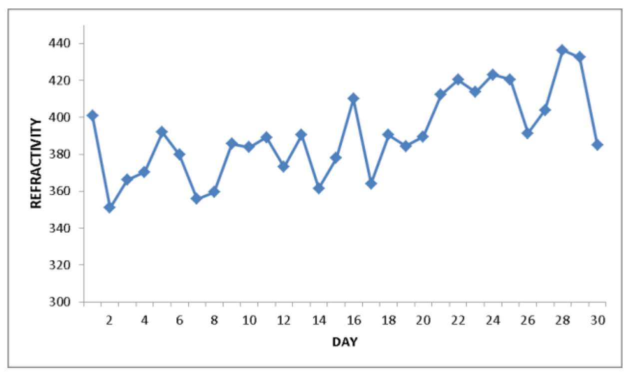

Fig. 5. Variation of surface refractivity over Minna for rainy season.

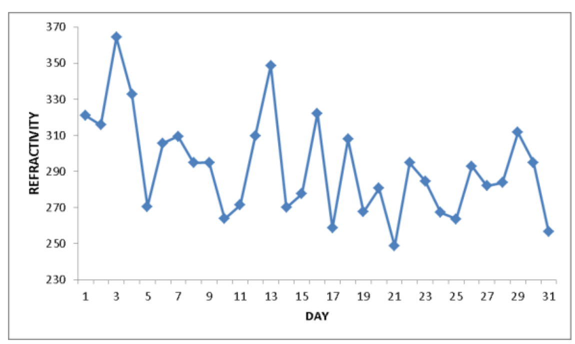

Fig. 6. Variation of surface refractivity over Minna for dry season.

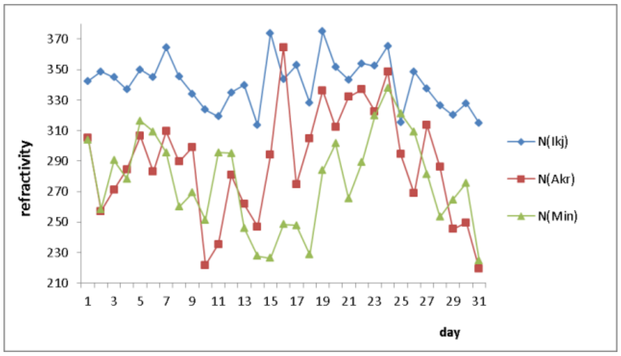

Fig. 7. Latitudinal Variation of Refractivity Over Lagos, Akure and Minna.

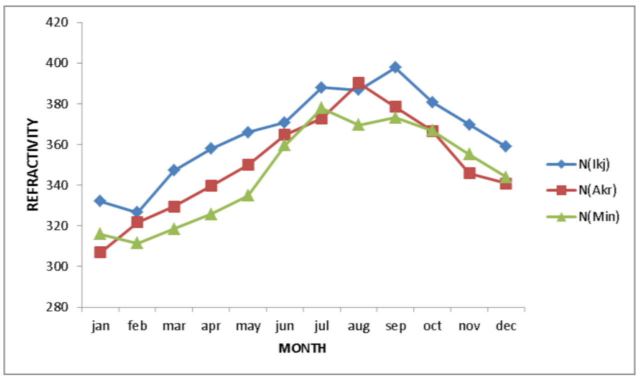

Fig. 8. Seasonal Variation of Refractivity Over Lagos, Akure and Minna.

V. CONCLUSION

Surface radio refractivity varies with the time of the day as well as the seasons of the year in the three stations of Lagos (Ikeja), Akure and Minna.

The values of refractivity in all the three stations are generally higher during the rainy season than during the dry season. Hence, higher radio power losses during the rainy season. In fact, in practical situations, a radio path will certainly encounter several obstructions and the exact computation of the total diffraction loss is cumbersome. As a result of this, the power output from the radio transmitter would be increased in order to offset the losses in the coastal areas of Lagos and the rainforest area of Akure.

Humidity has water component, which will seriously affect transmission thereby causing absorption (attenuation) of radio wave signals. Refractivity equally exhibits wave bending tendencies resulting in losses to some of the signals thus introducing attenuation. Radio signal transmission efficiency is higher in areas with low refractivity such as Minna area.

The diurnal and seasonal variations of refractivity are much more influenced by the variation of water vapour pressure than the variation of any other atmospheric parameter, hence higher values during the rainy season in the three locations.

ACKNOWLEDGMENT

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Annex

Table 1: REFRACTIVITY VALUES CALCULATED FOR JANUARY 2010

Name of Station: LAGOS (IKEJA) Longitude: $3^0$40'E

Elevation: 39m (129ft) Latitude: $6^0$35'N

Year: 2010 Month: January

DAY	T(^{0}C)	T(K)	RH	P(hPa)	es(mbar)	E(mbar)	N
1	23	296	87	911	28.08	24.42	342.53
2	24	297	88	911	29.82	26.24	348.72
3	25	298	85	897	31.66	26.91	344.79
4	25	298	81	885	31.66	25.64	336.84
5	25	298	87	901	31.66	27.54	350.04
6	25	298	87	881	31.66	27.54	344.83
7	24	297	92	959	29.82	27.43	364.21
8	23	296	98	872	28.08	27.52	345.24
9	23	296	93	850	28.08	26.11	333.99
10	23	296	87	827	28.08	25.55	323.74
11	24	297	91	770	29.82	27.73	319.24
12	24	297	87	901	29.82	25.94	334.84
13	25	298	91	847	31.66	28.81	339.74
14	25	298	87	762	31.66	27.54	313.58
15	25	298	97	948	31.66	30.71	373.77
16	24	297	88	893	29.82	26.24	343.50
17	25	298	89	906	31.66	28.18	352.73
18	25	298	85	839	31.66	26.91	328.16
19	25	298	92	971	31.66	29.13	374.94
20	24	297	86	933	29.82	25.65	351.45
21	25	298	80	913	31.66	25.33	343.36
22	25	298	84	934	31.66	26.59	353.86
23	25	298	79	956	31.66	25.01	352.43
24	25	298	81	990	31.66	25.64	365.49
25	23	296	73	872	28.08	20.50	315.35
26	23	296	79	971	28.08	22.18	348.72
27	24	297	81	901	29.82	24.15	337.27
28	24	297	87	833	29.82	25.94	326.55
29	25	298	84	805	31.66	26.59	320.01
30	25	298	80	855	31.66	25.33	327.73
31	25	298	86	778	31.66	27.23	314.88

NOTE:

RH = Relative Humidity

P = Pressure

es = Saturated Water Vapour

e = Water Vapour N = Refractivity

Table 2: Computed Refractivity values for Three Stations for January 2013

DAY	N(Ikj)	N(Akr)	N(Min)
1	348.42	310.41	320.94
2	372.46	307.49	315.86
3	379.58	305.41	364.33
4	345.69	313.58	332.55
5	325.65	325.65	270.51
6	345.28	334.56	305.55
7	373.60	326.50	309.40
8	379.88	366.15	294.80
9	366.91	337.05	294.88
10	326.45	299.89	263.91
11	336.18	336.18	271.36
12	330.71	350.00	309.58
13	353.99	349.09	348.69
14	359.31	358.01	269.95
15	355.75	383.80	277.64
16	364.31	339.51	322.12
17	331.83	359.96	258.66
18	394.77	404.91	307.95
19	358.34	314.48	267.53
20	321.47	372.09	280.64
21	328.06	353.29	248.69
22	325.38	356.41	294.78
23	368.39	365.74	284.69
24	307.28	289.60	267.35
25	346.34	335.26	263.59
26	373.60	314.19	292.95
27	347.51	345.15	282.02
28	361.80	307.94	283.72
29	335.57	324.00	311.67
30	326.66	309.56	294.90
31	296.70	273.30	256.80