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Seasonal and latitudinal variations of surface radio refractivity over Nigeria

Sanyaolu Modupe Eunice[1], Sanyaolu Olufemi[2]
[1]Department of Physical Sciences, Faculty of Natural Sciences, Redeemer's University, Ede, Nigeria
[2]Department of Mechanical Engineering, Faculty of Engineering, Redeemer's University, Ede, Nigeria

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ABSTRACT

Refractivity is a significant challenge of radio signal propagation. As it often distorts or leads to loss of signals. The seasonal and latitudinal variations of surface refractivity at three Nigerian tropospheric Observatory stations in Nigeria, namely Port-Harcourt, Lagos, and Makurdi, are presented in this paper. Values of monthly averages of pressure, temperature, relative humidity, and water vapour from the stations were used to compute surface refractivity at each station. The results show that the values of surface refractivity increase from the arid region in the north to the coastal area in the south. There was an increase in the values of surface radio refractivity from the minimum value of about 332.83 N-units at Makurdi station to a maximum value of 386.69 N-units at Lagos station. Seasonal variations are seen to be caused by weather conditions. The values of the surface refractivity increased significantly in the wet season and reduced in the dry season. It also shows that the values of surface radio refractivity are affected by the meteorological components mentioned above. The result of this study is needed for effective planning of good signal reception in these stations.

Corresponding Author:

Sanyaolu Modupe Eunice
Department of Physical Sciences, Redeemer's University
Ede, Osun State, Nigeria
Email: sanyaolum@run.edu.ng

1. INTRODUCTION

Radar beams, television signals, radio waves, and light rays are common examples of electromagnetic waves. These waves can be used to transmit information or energy over long distances. In wave propagation, the meteorological components and the frequency of operation determine the performance of the medium of propagation of the electromagnetic waves [1].

The troposphere, also called the lower atmosphere is the area of the atmosphere that reaches heights of 8 to 10 kilometers at arctic latitudes, 10 to 12 kilometers at mild latitudes, and 16 to 18 kilometers at the equator [2]. It is in the layer of the atmosphere that the majority of the meteorological events happen, such as rain, hurricanes, lightning, cyclones, snows, and fronts [3]. In the troposphere, the percentage of the gas components does not vary with height. It remains the same as it is at the surface [4]. The only exception is the water-vapor content which is majorly dependent on the seasonal changes and sharply decreases with height. The cause of the decrease in the temperature of the air with height is the near transparency of the troposphere to sun rays [5]. The bulk of the solar energy is absorbed by the earth's surface. The heated earth's surface is, in turn, a source of thermal radiation which heats the troposphere in an upward direction [6]. The troposphere is heated in part by convective air movement. The air near the ground warms up and flows higher, making room for cooler air that then becomes heated and moves upward. The non-uniform heating of ground areas produces ascending and descending air currents which result in turbulence and the mixing of air masses vertically, which decides the temperature condition in the troposphere [7].

The water that makes up the water vapor in the troposphere evaporates from the surface of oceans, water reservoirs, and the sea. The water vapour rapidly decreases with height. It is further assumed that the pressure and temperature decrease upward at fixed rates, called the standard temperature lapse rate [8], [9]. The troposphere is adopted to have atmospheric pressure of approximately 1,013 millibars, relative humidity of 60 percent, and a sea-level temperature of 15 °C [10].

The atmosphere and free space are very distinct, and the observed air-mass parameters are sufficiently varied to cause only slight variations in the propagation speed. Because they may produce radar ray refraction and lessen noticeable changes in the direction of propagation, these minute adjustments are significant [11]. Technology is improving daily, and the desire to grow with technology is on the increase, especially in microwave applications. Refractivity is one of the main challenges of radio propagation. The atmosphere, being a non-uniform medium, is often characterized by variations in its meteorological parameters such as temperature, relative humidity, water vapour and pressure. It will be expected that the vertical gradient of the index of refraction results into the bending of radio waves just the same way light rays get refracted as it changes medium of propagation of different optical density [12]. The gradient, if large enough, can cause reflection of the radio waves. [13], [14].

Researchers in Nigeria, such as [1], [3], [13], [15]-[22] have worked on the effect of atmospheric factors on radio propagation, but latitudinal variations of some specific locations considered in this work have not been dealt with extensively considering the two major seasons usually experience in Nigeria.

2. BACKGROUND

The relative index $n = \sqrt{\epsilon_r}$ of the troposphere fluctuates over time and location. (ϵ_r is the relative permittivity). Since n is always close to unity, it is the practice to use the so-called refractivity, N, which is the difference of the refractive index value from unity in parts per million [23]:

$$(n-1)10^6 = K_1 \frac{p}{T} \quad (1)$$

where p, T and K_1 represent the pressure (mbar), absolute temperature and value of 77.6, respectively. In dry air, ($(n-1)10^6$)is termed the "radio refractivity (N units) [24]. However, the refractive index when there is a mixture of water vapour e (mbar) to the air is expressed by [25].

$$N = \frac{77.6}{T}\frac{p}{T} - 5.6\frac{e}{T} + 3.73\ x\ 10^5 \frac{e}{T^2} \quad (2)$$

A widely established relationship for atmospheric refractivity index dependency on the pressure, the temperatures, and the water vapour are expressed as (3).

$$N = 77.6 + \frac{p}{T} + 3.73\ x\ 10^5 \frac{e}{T^2} \quad (3)$$

The water vapour e in terms of the temperature (°C) and relative humidity (H in %) is given as (4).

$$e = \frac{6.1121 exp\left(\frac{17.502t}{t+240.97}\right)}{100} H \quad (4)$$

This study analyses the seasonal and latitudinal variation of refractivity on the ground surface in three locations in Nigeria, which is a crucial factor in determining the good reception of radio waves.

3. METHOD

The equipment used in getting data for this study is the Nigerian Environment Climatic Observing Program data (NECOP) as shown in Figure 1. It is an equipment designed to establish a network of meteorological and climatological observing stations. The equipment is used to carry out essential measurement of meteorological and climatological variables which include, solar radiation, precipitation, soil moisture, relative humidity, temperature, atmospheric pressure, rain rate and other derived variables in real-time, through telemetry technology, with five minutes update cycles.

Figure 1. NECOP equipment used for the study

4. RESULTS AND DISCUSSION

Two years (2011-2012) data collected for the use of this study from the NECOP equipment were meteorological parameters such as: pressure, temperature water vapour and relative humidity. Measurement of the parameters were collected from three stations (Lagos, Port-Harcourt, and Makurdi). The latitudinal parameters, the minimum and maximum, refractivity values for the study period are shown in Table 1.

Table 1. Latitude, minimum and maximum refractivity values of the study locations

Station	Latitude	Minimum refractivity	Maximum refractivity
Port-Harcourt	04º 40º N	375.2	380.33
Lagos	06º 52º N	377.24	386.69
Makurdi	07º 43º N	332.83	372.97

Table 2 shows the temperature, pressure, relative humidity (RH), water vapour, and the equivalent surface refractivity values in Port-Harcourt. It is observed that the temperature in Port-Harcourt ranged between 26.17 ºC and 28.36 ºC. The RH is also high. This is because this location is on the coastal line. Therefore, the refractivity values are high all through the months.

In Table 3, similar trend was observed for Lagos, the temperature and RH are almost constant with little variations and having high refractivity values throughout the month. The least value of refractivity is seen in January which is the peak of dry season to be 375.2 N-units. This contradict what is seen in Makurdi from Table 4 as high refractivity only occurred in the raining months.

Figure 2 and Figure 3 shows seasonal variations of temperature and RH at the study locations. As mentioned earlier, the temeprature of Lagos and Port-Harcourt follows the same pattern while that of Makurdi had a drift having increase from February to March before reducing to the same level with Lagos and Portharcourt and thereafter increase in November (dry season). The relative humidity shows an interwoven pattern between Lagos and Port-Harcourt, however, in Makurdi, the RH level is seen to be low from January to March before it moves high and become almost stable till october before it experience a fall till December.

Table 2. Average monthly values of meteorological parameters and corresponding refractivity in Port-Harcourt

Month	Temperature	Pressure	Relative humidity	Water vapour	Refractivity
January	27.63	1003.05	76.14	28.14	375.21
February	28.04	1003.91	76.96	29.16	378.88
March	28.36	1002.16	77.07	29.75	380.33
April	27.91	1002.36	76.55	28.78	377.13
May	27.37	1002.84	78.57	28.62	377.48
June	26.44	1003.72	81.73	28.18	377.42
July	25.42	1008.78	84.9	27.57	377.87
August	24.91	1010.33	87.09	27.43	378.53
September	25.8	1011.44	83.78	27.83	379.02
October	26.17	1006.66	81.98	27.83	377.17
November	27.21	1006.00	75.87	27.38	373.43
December	28.55	1004.20	75.00	29.27	378.56

Table 3. Average monthly values of meteorological parameters and corresponding refractivity in Lagos

Month	Temperature	Pressure	Relative humidity	Water vapour	Refractivity
January	27.70	1004.83	76.96	28.68	377.70
February	28.64	1007.03	76.26	31.09	386.68
March	29.07	1004.95	78.13	31.42	383.83
April	28.28	1002.46	79.55	30.56	385.77
May	27.79	1005.32	82.07	30.64	383.23
June	26.74	1004.89	84.41	29.64	381.59
July	26.11	1009.78	84.76	28.67	377.24
August	25.79	1009.64	82.87	27.51	381.24
September	26.20	1010.49	84.05	28.58	382.83
October	26.51	1005.14	81.93	29.42	380.26
November	27.76	1006.01	78.48	29.25	382.33
December	28.47	1003.85	79.84	31.01	385.75

Table 4. Average monthly values of meteorological parameters and corresponding refractivity in Makurdi

Month	Temperature	Pressure	Relative humidity	Water vapour	Refractivity
January	28.86	989.05	48.27	19.18	332.83
February	31.19	992.29	47.99	21.80	341.07
March	32.34	989.74	45.27	21.95	339.41
April	29.76	987.95	64.02	26.79	361.31
May	27.90	992.74	74.15	27.86	370.87
June	26.66	994.54	76.37	27.31	370.44
July	26.60	997.5	78.63	27.48	372.54
August	26.86	996.56	79.24	27.59	372.85
September	26.64	997.71	78.21	27.65	372.97
October	27.95	995.39	79.25	27.66	372.77
November	27.76	989.45	63.75	24.02	354.12
December	27.73	985.55	52.75	19.63	353.33

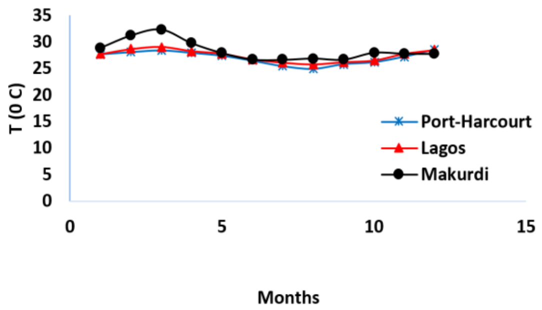

Figure 2. Seasonal variations of temperature at the study locations

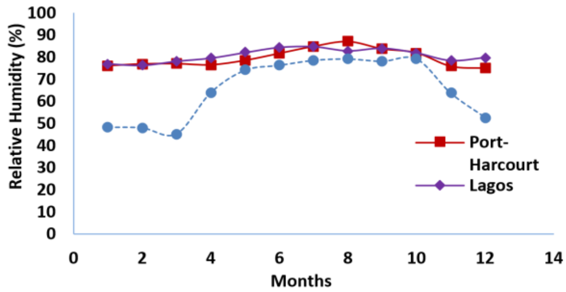

Figure 3. Seasonal variations of relative humidity at the study locations

The seasonal variations of surface refractivity over the areas of study are shown in Figure 4. It was observed that the variations of surface refractivity are seasonal in all the stations. The results show an increase in the values of surface radio refractivity from a minimum value of about 332.83 N-units at Makurdi to a maximum value of 386.69 N-units at Lagos station, which agrees with the work of [18].

It was also observed that the three stations follow the same trend having high values of refractivity with a minimum value of 373.43 N-units in November and a maximum value of 380.33 N-units in March for Port-Harcourt, a minimum value of 377.24 and 332.83 was recorded for Lagos and Makurdi in July and January respectively while the maximum values are 386.69 and 370.44 in February for Lagos and in June for Makurdi.

In Figure 4, Makurdi recorded a gradual increase in the values of refractivity from the month of April till October (which represents the wet season), where there is a slight decrease in the values of refractivity till December. In Lagos and Port-Harcourt, the values of refractivity increased gradually from January to February, after which there was a slight decrease in March. Continuous high values of refractivity were observed from the month of April to October (wet season). This is attributed to the fact that Lagos and Port-Harcourt are along the coastal line, the extensive cloud cover, and saturation of the atmosphere with a larger amount of water vapour during the period of study. This implies that there are high values of refractivity during the rainy seasons and a few times in the dry seasons.

Figure 5 to Figure 7 shows diurnal variations of radio refractivity in the study locations. In Figure 5, the wet term in Port-Harcourt was seen to be stable but slightly fluctuating between 140 N- units and 150 N-unit per hour, while the variation or the dry term is within 350 N-units. The diurnal variations in Lagos show that the wet term is within 140 N-units while that of the dry term was stable at about 380 N-units in a 24 hours observation. This is clearly shown in Figure 6. In Makurdi, Figure 7 revealed that the wet term variations were stable at 50 N-unit every hour while the dry term fluctuated between 280 N-units and 300 N-unit per hour. From the wet term, dry term, and total refractivity over the three locations under study, it was discovered that surface refractivity at these stations is being controlled by the wet term and not the dry term. The plots of the wet terms is the same as the surface refractivity.

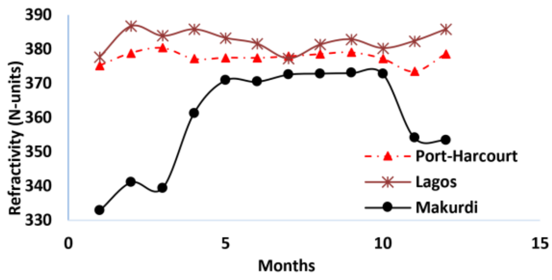

Figure 4. Seasonal variations of radio refractivity at the study locations

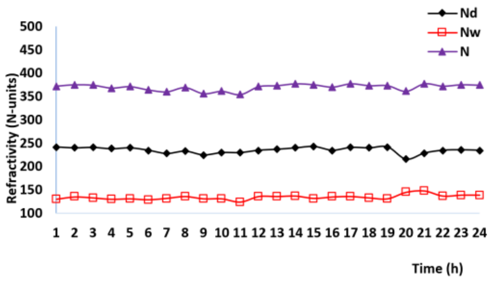

Figure 5. Diurnal variations of radio refractivity in Port-Harcourt

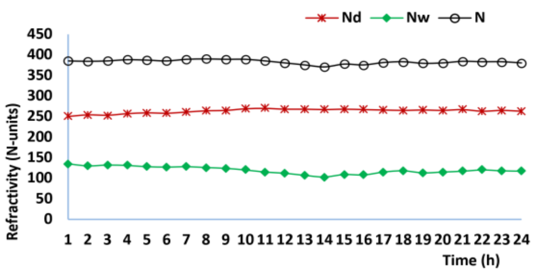

Figure 6. Diurnal variations of radio refractivity in Lagos

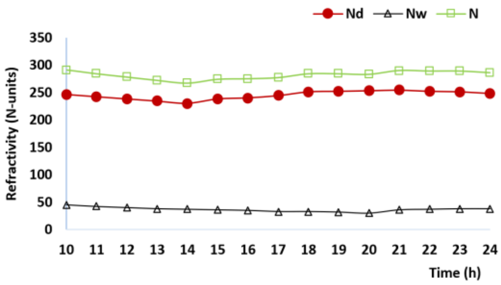

Figure 7. Diurnal variations of radio refractivity in Makurdi

5. CONCLUSION

The study of seasonal variations of surface refractivity over three stations in Nigeria has been analysed. The result displays that climatic conditions cause seasonal variation. The value of surface radio refractivity increased from a minimum value of 332.83 N-units in Makurdi station to a maximum value of 386.69 N-units at Lagos station, which is from the north (arid) to the south (coastal). The established results from this study will be very valuable for radio engineers in designing a microwave system for these regions.

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BIOGRAPHIES OF AUTHORS

Sanyaolu Modupe Eunice is a lecturer in Physical Sciences department of Redeemer's University Ede, Nigeria. She obtained both Ph.D. and MSc in Communication Physics from Redeemer's University Ede, Nigeria. With a BSc in Physics (Electronic) and a PGD in Electrical Electronics Engineering (telecommunication option). She speciallises in radiowave propagation, satellite communication systems, terrestrial and wideband propagation, wireless mobile and satellite networks, intersystem interferences, rf and microwave propagation. She is a Certified Engineer. She has authored and co-authored articles and conference proceedings in reputable journals as index in scopus in her field. She can be contacted at email: sanyaolum@run.edu.ng.

Sanyaolu Olufemi is a lecturer in Mechanical Engineering department of Redeemer's University Ede, Nigeria. He received the B.Eng. degree in Mechanical Engineering from Bells University of Technology, Ota, Nigeria, M.Tech. degree in Mechanical Engineering (Industrial/Production) from Ladoke Akintola University of Technology, Ogbomosho, Nigeria. He is currently on his Ph.D. degree in Mechanical Engineering from the same university. His research interests include Design and Engineering Anthropometry, Manufacturing Technology, Ergonomics, and Machine. He is a Certified Engineer. He can be contacted at email: sanyaolufemi@run.edu.ng.