Diurnal and Seasonal Variability of Radio Refractivity Over Coastal Nigeria

E. T. Omotoso [1*] and F. Olajide-Owoyomi [2]
[1]Department of Physics, Federal University of Technology, Akure, Nigeria.
[2]National Institute for Space Research, San Jose Dos Campos, Sao Paulo, Brazil.
*Corresponding E-mails: *omotosoemmanuel13@gmail.com
Phone numbers: +2348066218445 and +5512996529660.

ABSTRACT

In this paper, one-year meteorological data from 2015 were obtained from the European Center for Medium-Range Weather Forecast (ECMWF) for seven stations located in the seashore region of Nigeria. The study focused on the diurnal, seasonal, and annual fluctuations of the Earth's atmospheric refractive index and their impact on radio signals operating at microwave frequency bands over these locations. Analyses revealed that variations in refractivity significantly influence the reliability, range, and quality of microwave signals. Maximum values of surface refractivity were observed during the disturbed period at midday (12:00 hour LT), with values ranging from 405 to 420 N-units, while minimum values between 380 and 400 N-units were recorded during the quiet periods, particularly between 00:00 and 06:00 hour LT and late evening at 18:00 hour LT. Additionally, the results showed that higher refractivity values occurred during the wet season (March to May and October to November), associated with increased signal bending and enhanced propagation range. Conversely, lower refractivity values were observed during the dry season (December to February), resulting in reduced signal strength and range. These seasonal and diurnal trends indicate that atmospheric refractivity fluctuates proportionally with temperature and humidity changes, causing propagation anomalies such as multipath fading, ducting, and interference. Understanding these variations is crucial for the effective design and planning of microwave communication systems in regions with significant refractivity fluctuations. The study provides insights into the influence of climatic factors on signal behavior, which is essential for optimizing radio link performance in coastal regions.

Keywords: Radio refractivity, Microwave communications, Signal propagation, Coastal region, Atmospheric fluctuations, Link reliability.

INTRODUCTION

When predicting and analyzing the performance of terrestrial radio communication links, the refractive index is a crucial parameter as it significantly affects the propagation of radio waves, which in turn influences the efficiency of communication systems (Adegboyega, 2013). Variations in refraction can cause substantial changes in the power levels received, affecting both target and non-target receivers (Ali et al.,

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2012; Hassan et al., 2012). To obtain reliable communication links, numerous criteria, such as antenna heights and gains, power levels, path profile, distance, geographical location, and atmospheric conditions and properties must be taken into consideration in the design/planning phase. Research has shown that variations in the refractive index of the atmosphere, caused by uneven spatial distribution, can lead to adverse effects like multipath fading and signal interference (Ayantunji et al., 2011). Diffraction-induced attenuation also plays a key role in designing dependable ground-to-ground microwave communication systems, as well as in the accurate tracking of celestial objects, satellites, and missiles (Dissanayake et al., 1997). Building on the findings of Bettouche et al. (2019), regarding the long-term evolution of surface refractivity in Arctic regions, it is evident that climate parameters can fluctuate significantly from season to season and are often unstable in certain geographic areas (Falodun and Ajewole, 2006). There can be significant random variations year on year and may be cyclic variations or longer-term trends. Variations in climate conditions suggest that the refractive index (R) and its gradient (dR/dr), where dr represents a change in altitude, may fluctuate accordingly..

The main contribution of this paper is to consider annual, seasonal and diurnal fluctuation and the evolution of the meteorological parameters in the year 2015 and analyze their impact on the above-mentioned indices. Kolawole (1980) reported that surface refractivity levels, reduced to sea level, range from approximately 390 in southern coastal regions to about 280 in the northern regions of Nigeria..

This is in agreement with (Adebanjo, 1977) but slightly differs from (Owolabi and Williams, 1970) due to the elevation dependence of Ns. Oyedum and Gambo (1994) found comparable results, with a correlation coefficient of 0.73 between surface refractivity (Ns) and VHF field strength values extending beyond the horizon in Northern Nigeria. Oyedum (2018) showed that based on Ns variability, substantial climate-related differences exist between the seasonal variability of VHF field strength and radio horizon distance in two Nigerian stations of Lagos (06°35′N, 03° 20′E) on the Atlantic coast and Kano (12° 03′N,06° 42′E) in sub-Sahara Northern Nigeria.

Fluctuations in the radio refractive index can alter the trajectory of radio waves during propagation. Under standard atmospheric conditions close to the Earth's surface, the refractive index is typically around 1.0003 (Freeman, 2007).

DATA AND DATA ANALYSIS TECHNIQUES

One year (January 2015 to December 2015) satellite data of meteorological parameters (temperature, atmospheric pressure and relative humidity) at four synopsis hours (0 hours, 6 hours, 12 hours and 18 hours local time LT) were obtained from the ECMWF based at Shinfield Pack, Reading, United Kingdom with resolution 0.25 by 0.25. The data were obtained for seven (7) different locations Rivers (Portharcourt), Delta (Warri), Cross River (Calabar), Ondo (Arogbo), Akwa-Ibom (Oron), Bayelsa (Yenagoa) and Lagos (Lagos Island) States all within the coastal region of Nigeria. Table 1. presents the climatic and geographical characteristics of various study sites, including Rivers, Delta, Cross River, Akwa Ibom, Bayelsa, Ondo, and Lagos states. Each entry lists the latitude, longitude, average yearly temperature, relative humidity, and annual rainfall. This dataset was utilized to assess total impairments on radio paths at centimeter and millimeter-wave frequencies using ITU models, specifically applying DAIS with higher modulation schemes like QAM and QSPK.

The characteristics of the study locations are presented in the table below.

Table 1: Characteristics of each of the study sites.

STATES	**LATITUDE (N)**	**LONGITUDE (E)**	**AVERAGE YEARLY TEMP. (°C)**	**AVERAGE YEARLY R.H (%)**	**ANNUAL RAINFALL (mm)**
RIVERS	4° 45′	6° 50′	26.69	83.40	2294
DELTA	5° 30′	6° 00′	27.26	83.90	2768
CROSS RIVER	5° 45′	8° 30′	26.10	85.10	2750
AKWA IBOM	5° 00′	7° 50′	26.29	85.00	2878
BAYELSA	4° 45′	6° 05′	26.70	83.80	2899
ONDO	7° 10′	5° 05′	26.86	84.00	2129
LAGOS	6° 30′	3° 45′	27.00	84.90	1693

To obtain the radio surface refractivity (N_s), water vapour pressure (e) is first deduced using (ITU-R P. 530-14, 2012):

$$e = \frac{6.1121H}{100} exp \frac{17.502t}{t + 240.97} \quad (1)$$

Subsequently, N_s can be obtained as:

$$N_s = \frac{77.6}{T}\left(P + 4810\frac{e}{T}\right) \quad (2)$$

where H (%) is the relative humidity of the atmosphere and t is temperature (^oC), N_s is the atmospheric surface refractivity, T is the temperature (K), P is the atmospheric pressure (hpa) and e is the water vapour pressure (hpa).

The computed values were used to estimate refractivity on diurnal and seasonal across the selected locations.

RESULTS AND DISCUSSION

The surface meteorological data of temperature, relative humidity, and pressure were used to calculate the surface refractivity N_s. Fig. 1 depicts the surface refractivity for a typical day April 1, 2015, representing the transition month between dry and wet season. The result showed increase in refractivity value from 0 hr LT between 385 N-units and 405 N-units to 12 hrs LT (peak) between 405 N-units to 420 N-units and reduction in refractivity at 18 hrs LT between 400 N-units and 420 N-units. The peak value of N_s obtained during the 12 hrs LT may be attributed to the activity of solar radiation, as the intensity of incident solar radiation increased, temperature values increased while the values of humidity reduced.

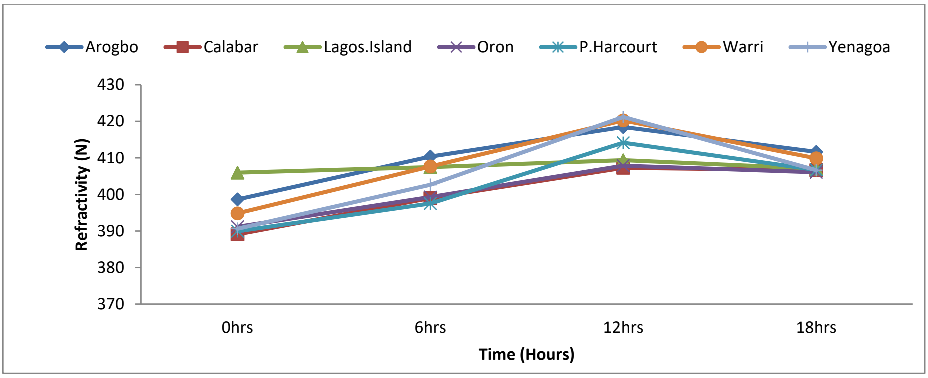

Figure 1: Diurnal variation in all the locations based on a typical day (April 1, 2015).

Figs 2-8 also shows the influence of seasonal trend on surface radio refractivity in all the stations. Average seasonal surface refractivity N_s at all the study locations shows a similar pattern. In Figure 4, the graph shows a sine wave with the refractivity displaying maximum trough with a very strong dip around August which is more significant in Lagos-Island region.

This drop in August may be attributed to August break known for period of reduced rainfall. The double peaks with the first peak between March and May and the second peak between October and November have the highest mean values for N_s ranged between 405 N-unit and 420 N-units. The N_s at the double peak are conspicuously high as expected because water vapour decreases with increasing height from the surface. This result agrees with the work of Adeyemi and Emmanuel (2011). The result also indicated higher N_s value during the raining season months around April and May and lower N_s during the dry season months (December to February). This may be attributed to the fact that they are close to the Atlantic Ocean.

Based on annual variation, the results obtained in all the study locations showed the same trend with highest values of N_s at 12 hrs LT which may be attributed to the activity of solar radiation, followed by 18 hrs, 6 hrs and the least at 0 hrs LT and the values ranged between 385 and 410 N-units. However, when comparing the variation of average surface radio refractivity of all the locations for the 1-year period, higher values were observed in Lagos Island at 0 hrs, 6 hrs and 18 hrs while Arogbo recorded the highest value at 12 hrs (Figures 9-12).

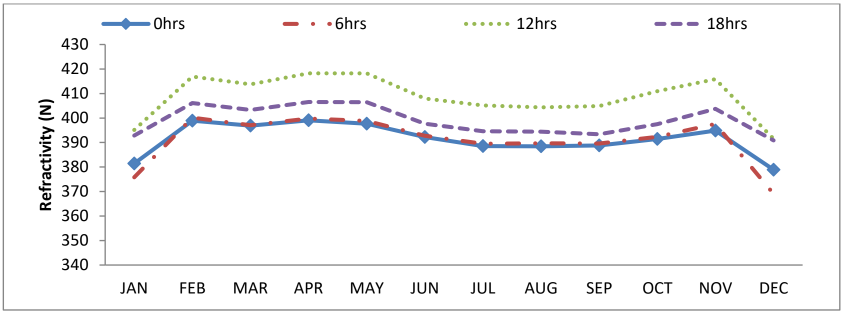

Figure 2: Seasonal variation of surface refractivity in Arogbo during the year 2015

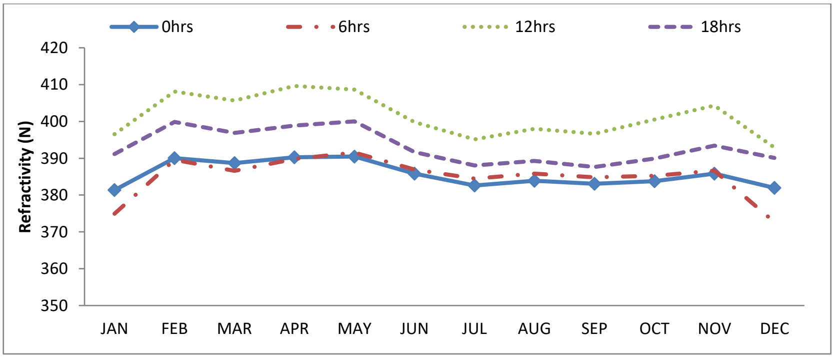

Figure 3: Seasonal variation of surface refractivity in Calabar during the year 2015

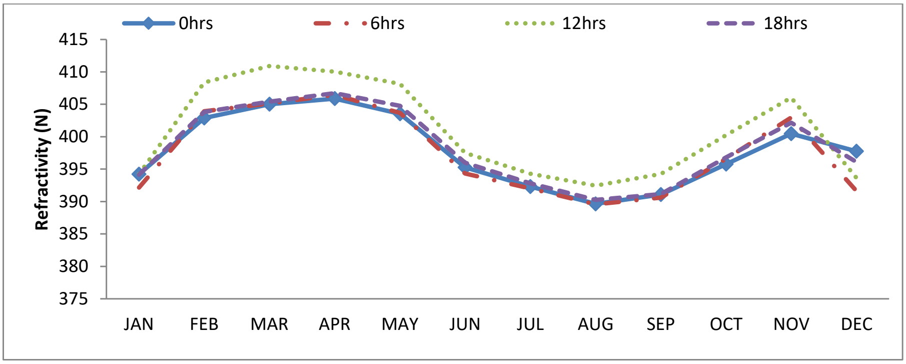

Figure 4: Seasonal variation of surface refractivity in Lagos-Island during the year 2015

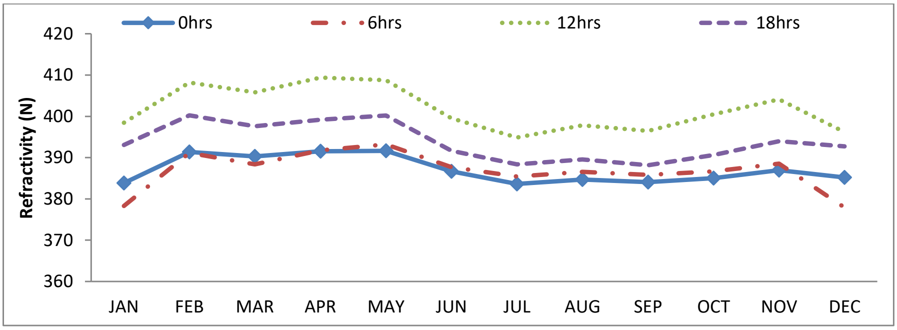

Figure 5: Seasonal variation of surface refractivity in Oron during the year 2015

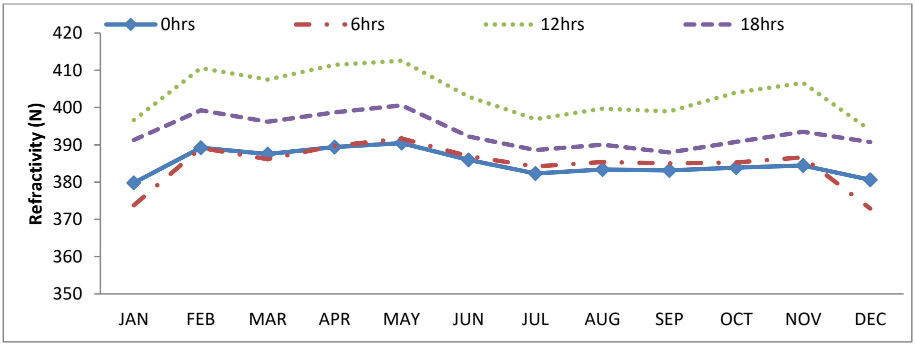

Figure 6: Seasonal variation of surface refractivity in Port-Harcourt during the year 2015

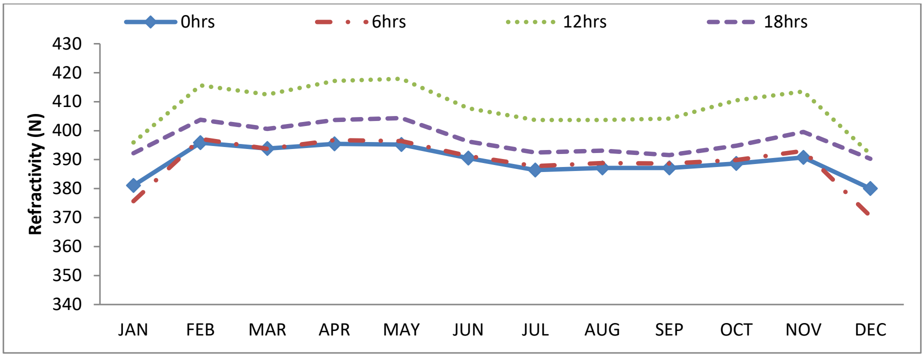

Figure 7: Seasonal variation of surface refractivity in Warri during the year 2015

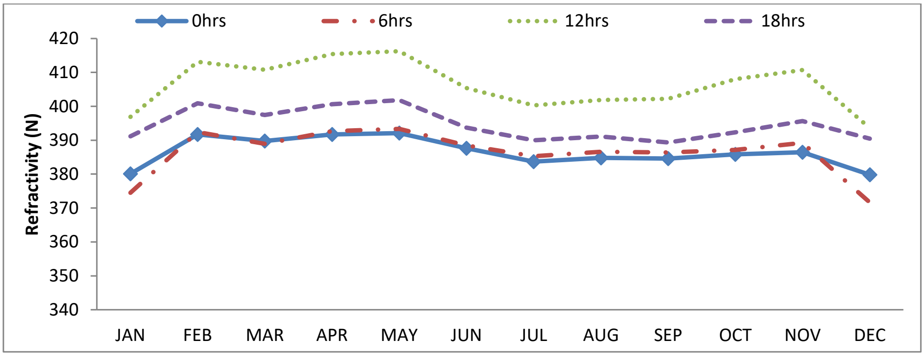

Figure 8: Seasonal variation of surface refractivity in Yenagoa during the year 2015

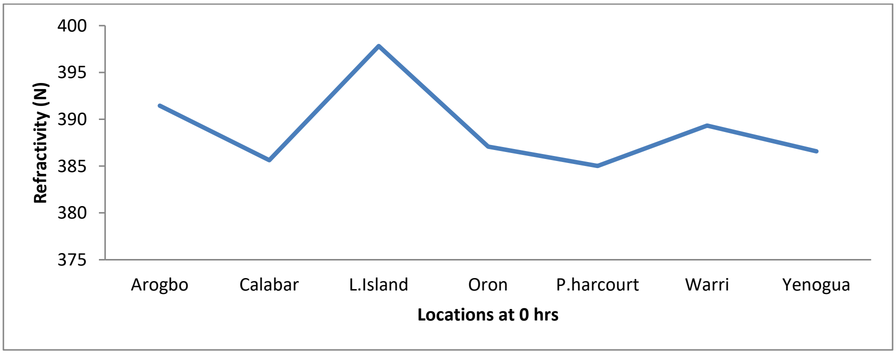

Figure 9: A year variation of all the study location at 0 hrs

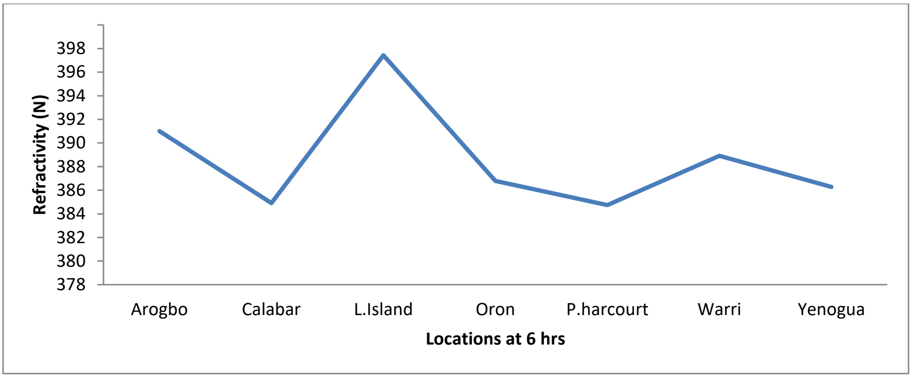

Figure 10: A year variation of all the study location at 6 hrs

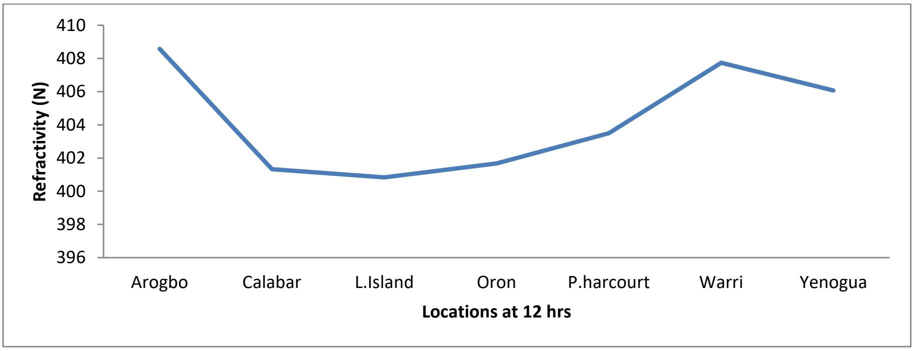

Figure 11: A year variation of all the study location at 12 hrs

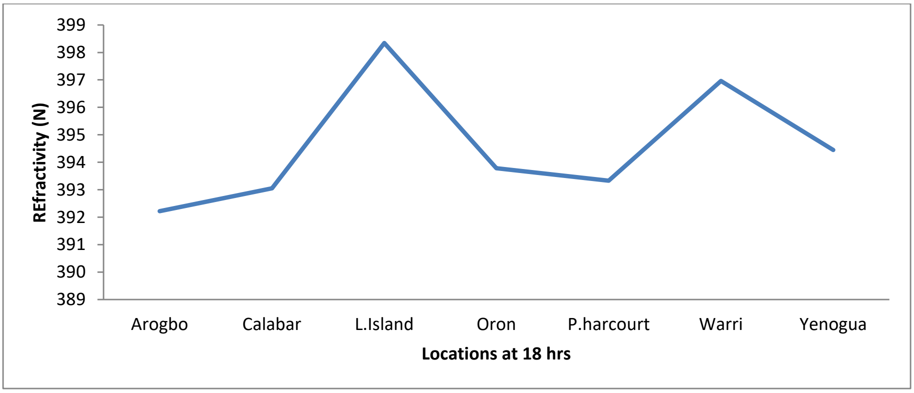

Figure 12: A year variation of all the study location at 18 hrs

SUMMARY

Atmospheric refractivity is a critical parameter influencing the reliability and performance of microwave communication systems. The COSMIC/FORMOSAT-3 mission has provided valuable insights into atmospheric refractivity, which are essential for improving weather forecasting and telecommunications (Ho *et al*., 2020). The integration of GNSS radio occultation data has shown to enhance the prediction of severe weather events, thereby providing critical information for the optimization of satellite communication systems (Gao *et al*., 2021). Research has shown that variations in refractivity can lead to significant propagation anomalies, especially in coastal and equatorial regions. The performance analysis of microwave radio refractivity highlights its significant influence on radio field strength and horizon distance, emphasizing the need for precise refractivity measurements in telecommunications systems (Adediji *et al*., 2014). Future research should focus on developing more robust predictive models that incorporate real-time meteorological data, as well as exploring the potential impact of climate change on long-term refractivity trends. Additionally, comparative studies between different climatic zones can provide further insights into the global applicability of existing models. For instance, Super refraction phenomena can significantly distort GPS radio occultation refractivity measurement, thereby affecting the accuracy of atmospheric models utilized in telecommunications (Xie *et al*., 2010). Similarly, this study found that variations in atmospheric refractivity particularly in coastal regions can lead to notable propagation anomalies that impact the performance of radio communication systems.

CONCLUSION

Earth’s atmospheric refractivity fluctuates annually, seasonally and diurnally in proportion to the intensity of sunlight and solar activities as peak values of atmospheric temperature was recorded during the afternoon periods and minimum values during the morning period and late evening hour. Recent studies highlight the ongoing challenges in satellite communications, particularly those related to atmospheric refractivity and its effect on signal transmission (Kodheli *et al*., 2021).

The maximum values of the Earth’s atmospheric refractivity for annual, seasonal and diurnal were recorded during the disturbed period (12:00 hour LT) while minimum values were recorded during the quiet period (00:00 hour and 06:00 hour LT) and late period 18:00 hour local time.

Also, minimum values of the Earth’s atmospheric refractivity were recorded in the dry season months (December to February) due to high temperature and low water vapor pressure during this period and maximum values of surface refractivity were recorded in the wet season months between March and May and also October and November due to low temperature and high-water vapor pressure during such period.

Further studies could explore the long-term impact of climate change on refractivity in tropical regions or analyze the effect of refractivity fluctuations on different frequency bands.

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