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Statistical analysis of the effects of relative humidity and temperature on radio refractivity over Nigeria using satellite data

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Meteorological data from the Department of Satellite Application Facility on Climate Monitoring (CM-SAF), DWD Germany have been used to study and investigate the effect of relative humidity and temperature on refractivity in twenty six locations grouped into for climatic regions aloft Nigeria (Coastal, Guinea savannah, Midland and sub Sahelian regions). The four years data collected ranged from 2004 to 2007 and was evaluated on their linear variation of refractivity on both temperature and relative humidity at different atmospheric level. The coefficient of determination (CD) was also determined for each relation. The results obtained establish the seasonal variation of temperature and relative humidity to refractivity across the region especially at low and mid-level. The coefficient of determination at both region is high for the variations measured against relative humidity and refractivity, while that of temperature and refractivity is low. This affirms that changes in relative humidity influence refractivity more than temperature at lower and middle level.

Key words: Refractivity, temperature, humidity, variation, atmospheric.

INTRODUCTION

Radio refractive index is an important parameter in determining the quality of UHF, VHF, and SHF signals. In characterizing a radio channel, surface (ground level) and elevated refractivity data are often required; and in particular, the surface refractivity is very useful for the prediction of some propagation effects (Bean and Dutton, 1968). The effect of atmospheric refractivity on the propagation of radio waves has been studied from the beginning of radio wave technology (Kerr, 1987). It has been established that the refraction of electromagnetic waves due to inhomogeneous spatial distribution of the refractive index of air causes adverse effects such as multipath fading and interference, attenuation due to diffraction on the terrain obstacles or so called radio holes (Lavergnat and Sylvain, 2000; Adediji and Ajewole, 2008). The refraction of radio signal through the

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troposphere has a direct effect on the design of reliable ground to ground microwave communication systems and the accuracy of tracking of radio stars, radio galaxies, satellites and missiles (Kolawole and Owonubi, 1982). Atmospheric refractivity is dependent on physical parameters of air such as pressure, temperature and water content. It varies in space and time due to physical processes in the atmosphere that are often difficult to describe in a deterministic way and have to be, to some extent, considered as random with its probabilistic characteristics (Martin and Vaclav, 2011). Jidong et al. (2008) reported that during warm season, radio refractivity gradient is more sensitive to moisture gradient in some selected locations in USA. They concluded that moisture has a more significant influence on the radar ray path calculation than temperature. Some other researchers worked on refractivity variation based on few available radiosonde station data in Nigeria (Adeyemi, 2004; Willoughby et al., 2000; Kolawole and Owonubi, 1982) and few experimental sites where sensors were mounted on a radio transmitter to access atmospheric data (Adediji and Ajewole, 2008). Their results show that refractivity values were normally high during the rainy season and low in the dry season.

This research work focuses on an in-depth analyses of seasonal variation of radio refractivity alongside with temperature and relative humidity at five atmospheric levels (925, 775, 600, 400, and 250 mb) grouped into three: Low Level: Surface - 925 mb; Mid-level: 775 - 600 mb; Upper level: 400 - 250 mb; in twenty six locations of four climatic regions over Nigeria. It also examines the linear regression between refractivity and temperature and refractivity and relative humidity. This study is important, because the lower atmosphere is not homogeneous (Zilinskas et al., 2012). This affects the electromagnetic (EM) wave propagation in the tropospheric layers. Worse propagation conditions lead to decreased power levels at the receiver and to increased fading on communication links (Ali et al., 2012). The meteorological conditions have a significant impact on radio wave propagation through the atmosphere. There are two climatic seasons that prevail within Nigeria, namely, the wet and the dry seasons. The weather in Nigeria is generally quite hot throughout the year, although there are variations in the climate in certain regions within the country. The southern part of Nigeria is relatively more humid and damp than the northern part of the country. Southern region is also influenced by the monsoons originating from the South Atlantic ocean, which is brought into the country by the maritime tropical (MT) air mass, a warm moist sea to land seasonal wind. Its warmth and high humidity give it a strong tendency to ascend and produce copious rainfall, which is a result of the condensation of water vapour in the rapidly rising air (Ajayi, 2009). The temperature ranges are almost constant throughout the year. The northern regions are much drier in nature in comparison to the southern parts. There are extreme weather conditions in the deserts of the Sahara. Annual rainfall totals are lower compared to the southern and central part of Nigeria. Rainy season in the northern part of Nigeria lasts for only three to four months (June to September). The rest of the year is hot and dry with temperatures rising as high as 40°C (Ekpoh and Nsa, 2011).

DATA AND DATA ANALYSIS TECHNIQUES

Average monthly temperature and relative humidity data for five different atmospheric pressure level (925, 775, 600, 400 and 250 mbar) which spanned between 2004 and 2007 were obtained from the archive of the Department of Satellite Application Facility on Climate Monitoring (CM-SAF), DWD Germany. The data from 26 locations grouped into four climatic region based on Olaniran and Sumner (1989) within the Nigeria troposphere were selected for this investigation (Figure 1). These regions are coastal (CT), guinea savannah (GS), midland (ML) and sahelian (SH) regions.

Refractivity was calculated from the raw data obtained using (ITU-R, 2012) recommendation.

$$N = (n-1)\times 10^{6} = \frac{77.6}{T}\left[P + \frac{4810e}{T}\right] \qquad \text{Equation 1}$$

where P is pressure (hPa) and T is temperature (K) (Brussaard, 1996; Adeyemi and Emmanuel, 2011).

Levels of temperature, relative humidity and refractivity were analysed using techniques applied by Balogun and Adedokun (1985), Adeyemi (2004) and Adeyemi and Emmanuel (2011), the profiles of temperature, relative humidity and refractivity were grouped into low level, *TL, RhL, NL* (surface - 925 hPa); mid-level *Tm, Rhm, Nm* (775 - 600 mb); and upper level *Tu, Rhu, Nu* (400 - 250 mb).

Statistical analysis

Linear regression and analysis of variance (ANOVA) techniques were used to quantify the relationship between temperature and refractivity and relative humidity and refractivity for each of the region. Using the excel package, coefficient of determination (CD), standard error (SE), gradient and probability f-significant at which null-hypothesis was rejected, were estimated for each of the linear regression in each region which provides a useful measure of variability between each of the two parameters at each region (Kimball et al., 1997).

RESULTS AND DISCUSSION

Monthly variation of temperature, relative humidity and refractivity

The average monthly variation of refractivity (*N*), relative humidity (*Rh*) and temperature (*T*) at two different atmospheric pressure levels (low and upper levels) over the four regions in Nigeria are presented in Figures 2 to

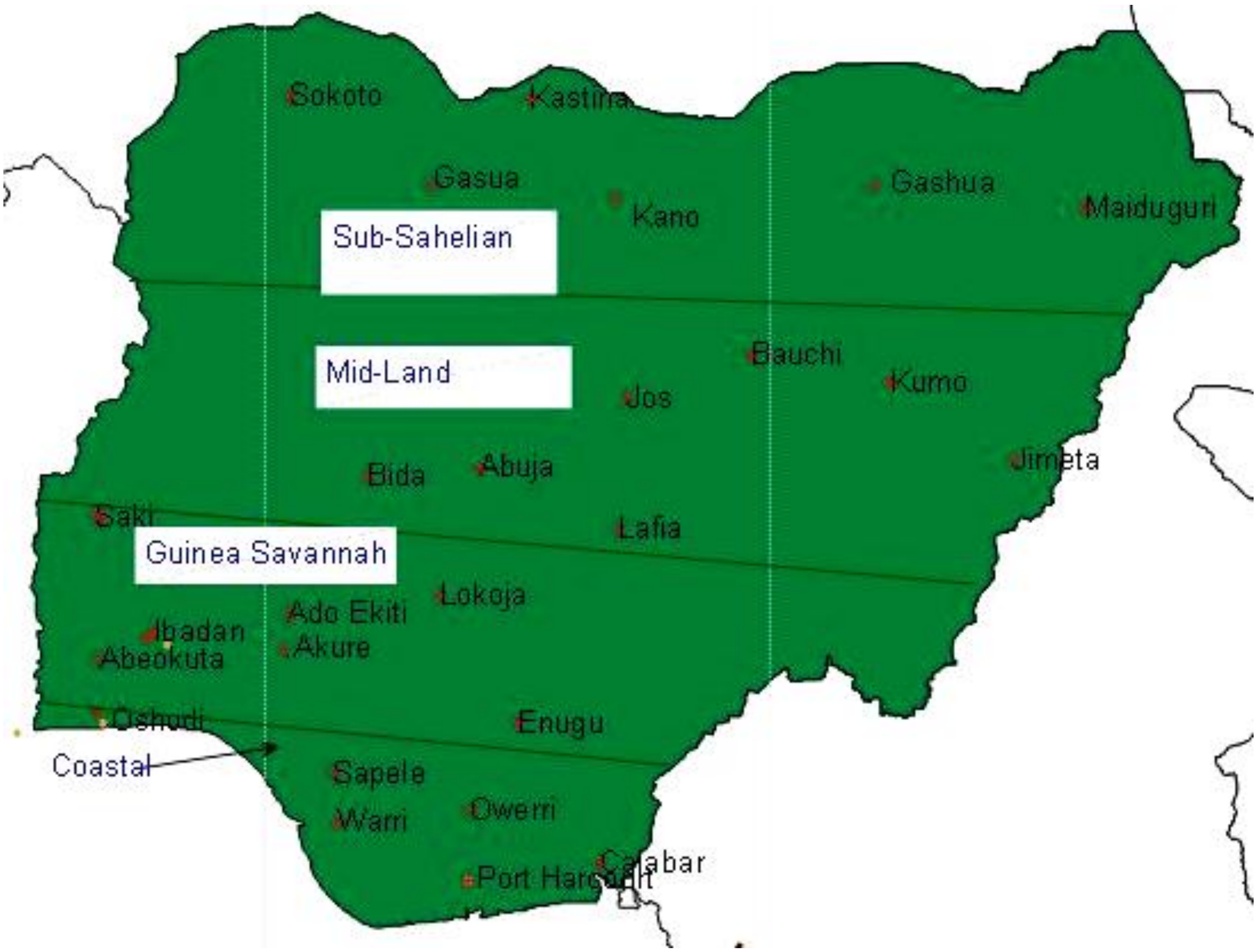

Figure 1. Map of Nigeria showing the study locations.

5. At low level, both *NL* and *RhL* have similar pattern of variation. Their values are high during the rainy months of March to October with partial dip in August at CT and GS with (NL= 325 N-unit, RhL = 90%) and (NL =330 N-unit, RhL= 78), respectively. Their values are however low in the dry months of November to February. During this period, the average values of NL and RL at CT and GS are 328.98 N-unit, 90.25% and 332.74 N-unit, 87.87% for rainy months and 326.99 N-unit, 81.91% and 318.95 N-unit, 73.55% for dry months, respectively. At ML and SH, the variation of NL and RhL are similar with high values during the rainy months of May to October and low value during the dry months of November to April. There are conspicuously low during the dry months. Their average values at these regions are 330.63 N-unit, 85.52% and 329.15 N-unit, 74.15% in the rainy month; and 295.34 N-unit, 45.05% in dry months, respectively. However, TL values were high at dry months and low at rainy months in all the regions with deep observable in August which is more noticeable at CT and GS. This can be attributed to the August break (a period of no rain in the southern Nigeria) associated to movement of international discontinuity (ITD). Average value of TL at CT, GS, ML and SH are 290.73, 291.88, 292.61 and 295.31 K in the rainy months and 292.08, 292.85, 294.76 and 295.84 K in the dry months, respectively.

At upper level (Figures 4 and 5), *Rhu* is partially high in rainy months and low in the dry months in all the region. Whereas *Nu* is zigzagly decrease and increase from January to December. *Tu* follow similar pattern as Nu, but in opposite direction. This shows the partial departure of water vapour at upper level of the troposphere. It also revealed that refractivity values are influenced by dry component of Equation 1. Average values of Nu, Rhu and Tu for CT, GS, ML and SH are 109.87 N-unit, 54.57%, 229.13 K; 109.82 N-unit, 60.07%, 229.11 K; 109.95 N-unit, 55.24%, 229.03 K and 109.85 N-unit, 51.70%, 229.03 K in rainy months, respectively. For dry

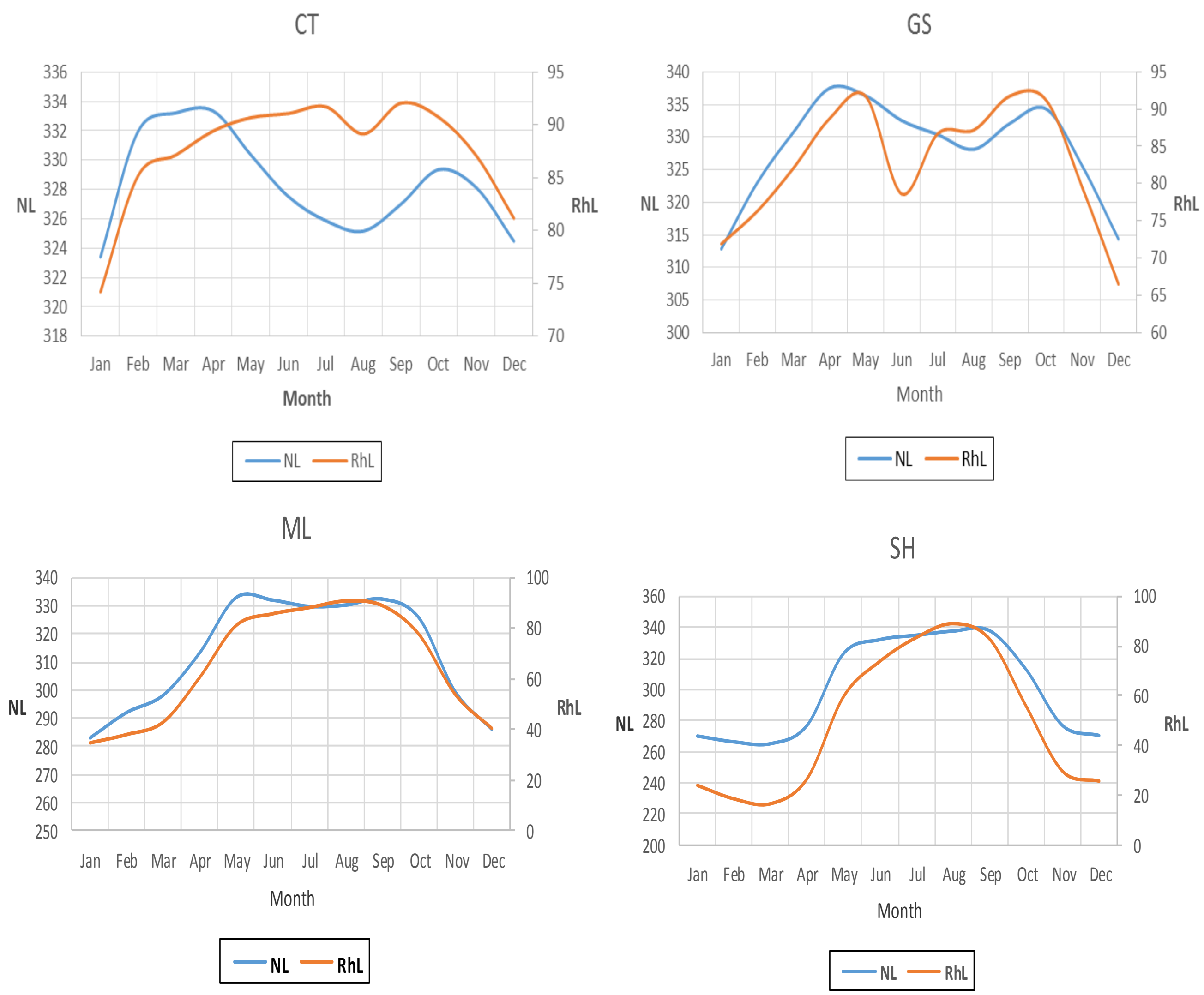

Figure 2. Average monthly variation of low level refractivity and relative humidity at (a) Coastal, (b) Guinea savannah, (c) Midland, and (d) Sahelian regions.

months, it is 109.67 N-unit, 39.19%, 229.25 K; 109.70 N-unit, 48.84%, 228.89 K; 109.64 N-unit, 38.86%, 229.11 K and 109.79 N-unit, 41.70%, 228.96 K.

Regression analysis

Tables 1 and 2 show the result of a linear fit of the relationship between N and T and relationship between N and Rh. This was done in order to estimate the extent to which each of the parameters correlates with the refractivity. They also show the coefficient of determination (CD), gradient, standard error (SE) and probability f-significant at which the null hypothesis was either accepted or rejected. Table 1 shows statistical regression between refractivity and temperature at low level, midlevel and upper level. As shown in Table 1, positive gradient is only noticeable at coastal region at low level while other regions in all the levels are negative. This implies that for every 1 unit increase in temperature, refractivity increases by an average of 1.37, whereas at guinea, midland and sahelian region, it decreases by 0.17, 4.47 and 2.948, respectively. Also, at midlevel and upper level, increase in temperature tends to the decrease in the refractivity in all the regions by the factors shown in Table 1. This may account for ducting phenomenon which normally pervaded in the coastal area. Weak CD was observed at coastal region and poor CD in all the remaining regions. Coefficient of determination shows weak relationship between

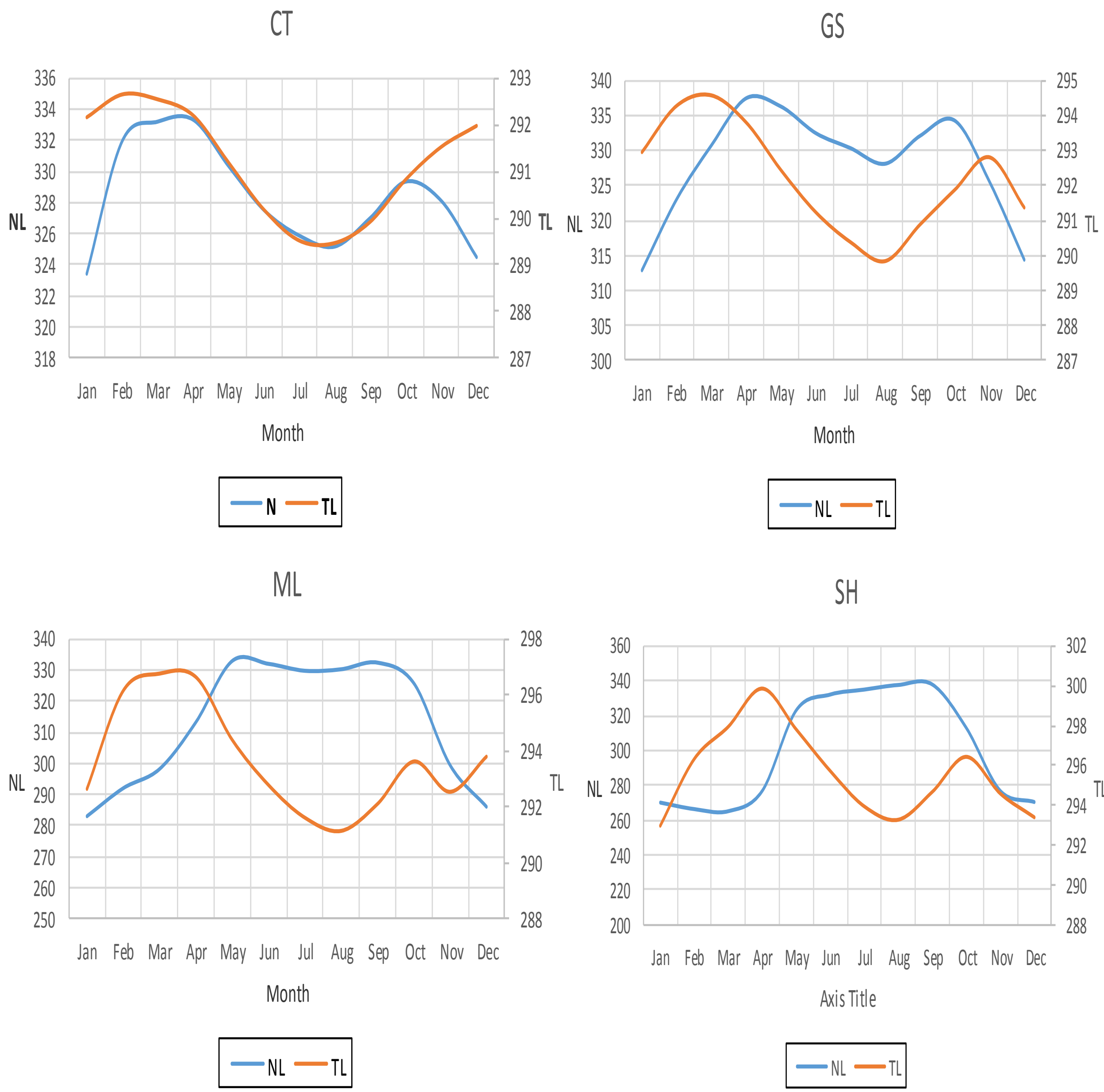

Figure 3. Average monthly variation of low level refractivity and Temperature at (a) Coastal (b) Guinea savannah (c) Midland and (d) Sahelian regions.

temperature and relative humidity at coastal region and poor association at the other regions at low level. At mid-level, there is fair relationship between T and N at coastal and midland, weak and poor at guinea savanna and sahelian regions, respectively. However, good relation exists at upper level in all the regions.

The null hypothesis is rejected when the f – sig. is less than critical level (f<0.05) for all the cases. Hence at low level, the null hypothesis is hereby accepted in all the regions since f is not significant (f sig. is greater than the critical value) (Table 1). This shows that the use of independent variable (temperature) has not assisted in predicting the dependent variable (refractivity) from the model. The performance of the model was encouraged at upper level, since the f sig. is less than critical values and the null hypothesis is hereby rejected.

From Table 2, f sig. is less than the critical value (0.05) at low level and mid-level in all the regions except in coastal region at low level where f sig. is 0.21. The null hypothesis is hereby rejected except at low level in the

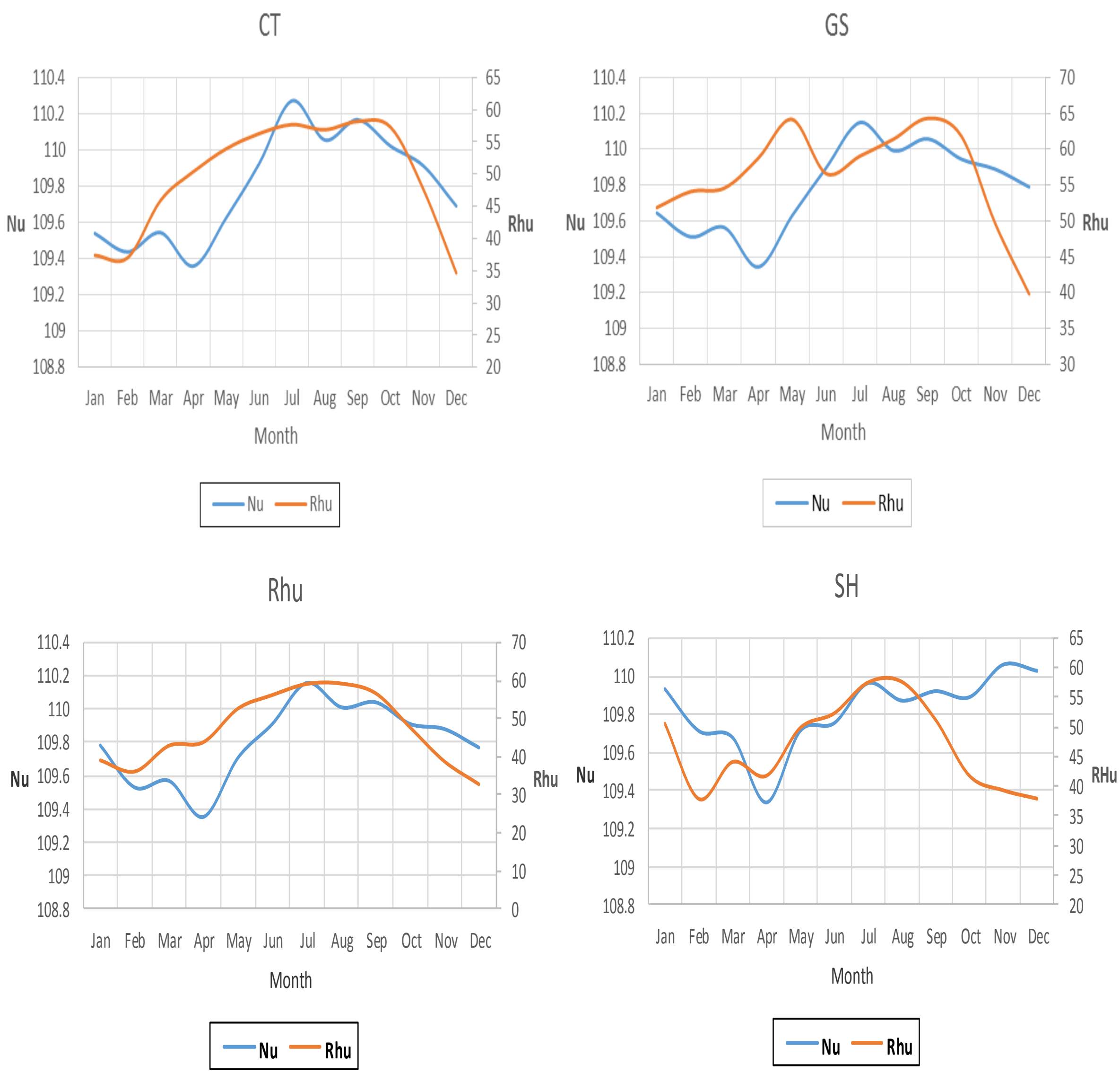

Figure 4. Average monthly variation of upper level refractivity and relative humidity at (a) Coastal (b) Guinea savannah (c) Midland and (d) Sahelian regions.

coastal region. This also shows the dependence of refractivity on the independent variable (relative humidity) at this level. The coefficient of determination, CD, is also high in all the regions both at low and mid-levels except at coastal region, where it is 14.8%. At the upper level, the performance of the model differed from one region to another. In the coastal and midland regions, the null hypothesis is rejected since f sig. is less than the critical value but the null hypothesis is accepted in guinea savannah and sub sahelian regions.

The slopes of the trend lines indicate the extent to which refractivity changes with a unit change in the values of the affected parameter. From Table 1, the temperature gradient, that is dN/dT is negative in all the regions and at all levels; this shows that the refractivity decreases with temperature (Ekpe et al., 2010). Positive relative humidity gradient, dN/dH is noticed in the entire region and at all levels. This shows that refractivity increases with humidity. Nevertheless, the rate of change of refractivity is much more depended on the relative humidity than temperature except for the coastal region at low level. This is in agreement with the finding of Smith and Weintraub (1953) in a similar investigation.

Table 2 shows the statistical relation between relative humidity and refractivity at three different levels of the troposphere. Small positive gradient are noticeable at all levels in all the regions. CD shows linear relationship between RH and N.

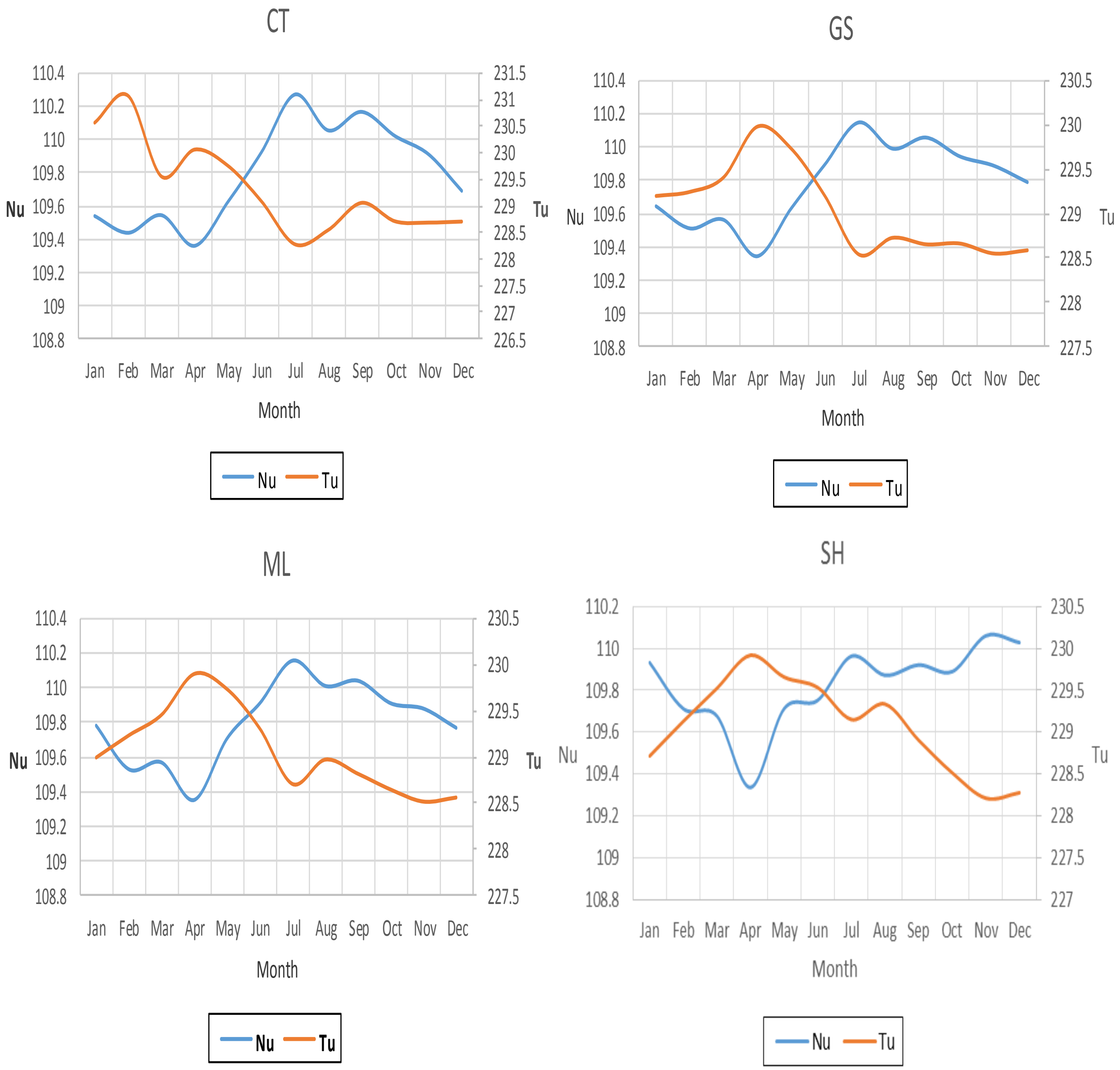

Figure 5. Average monthly variation of upper level refractivity and temperature at (a) Coastal (b) Guinea savannah (c) Midland and (d) Sahelian regions.

Table 1. Regression Results for Refractivity and Temperature over Nigeria.

Region	Low Level				Mid-Level				Upper Level			
	CD(%)	Gradient	SE	f-sig.	CD(%)	Gradient	SE	f-sig.	CD(%)	Gradient	SE	f-sig.
Coastal	23.00	1.370	0.794	0.116	34.00	-2.426	1.064	0.046	74.10	-0.440	0.082	0.000
Guinea savannah	0.10	-0.173	1.635	0.918	27.70	-3.836	1.961	0.079	72.10	-0.421	0.083	0.000
Midland	18.40	-4.473	2.982	0.165	39.90	-6.678	2.592	0.028	49.20	-0.356	0.115	0.011
Sub Sahelian	4.10	-2.948	4.522	0.529	2.10	-1.266	2.732	0.653	69.20	-0.304	0.064	0.001

*CD: Coefficient of determination (R^2); SE: standard error.

Table 2. Regression Results for Refractivity and Relative Humidity over Nigeria.

Region	Low Level				Mid-Level				Upper Level			
	CD (%)	Gradient	SE	f-sig.	CD (%)	Gradient	SE	f-sig.	CD (%)	Gradient	SE	f-sig.
Coastal	14.80	0.248	3.260	0.217	94.90	0.302	0.220	0.000	47.99	0.024	0.008	0.013
Guinea savannah	77.20	0.843	0.145	0.000	84.05	0.843	0.511	0.000	3.83	0.007	0.110	0.542
Midland	95.84	0.870	0.570	0.000	98.73	0.417	0.015	0.000	38.43	0.015	0.006	0.032
Sub Sahelian	97.68	1.108	0.054	0.000	99.30	0.474	0.013	0.000	0.50	0.002	0.009	0.827

*CD: Coefficient of determination (R^2); SE: standard error.

Conclusion

Analysis of refractivity, relative humidity and temperature aloft Nigeria revealed that the variation of refractivity vary seasonally from one region to other. At low level, variation of NL and RhL follow similar pattern which is high during the rainy and low during the dry months, while the case of temperature is a reverse. Influence of RhL and TL over NL is noticeable. In addition, the following trends were also discovered from the study:

(1) At low level, temperature increases northward and is much higher in the dry months than in rainy season.
(2) At coastal and guinea savannah regions, higher and almost uniform values of relative humidity and refractivity parameters are observed throughout the year (Figure 3b and c), mean values of Rh range between 52 and 76% at coastal region, and 47 and 74% in the guinea savannah region; and mean value of N range between 323 and 334 N-units in coastal and 312 and 336 N-units at guinea savannah.
(3) In the case of midland and sub sahelian regions, Rh and N parameter values during the dry season are quite lower than those of rainy season. A similar situation was noticed at mid-level.
(4) The distinction observed between the southern and the northern regions in relative humidity and refractivity may be attributed to the fact that the precipitation climatology of the two regions differ appreciably (Balogun, 1981; Garbutt et al., 1981).
(5) At the upper level, the variation of T or N does not have a particular pattern as it oscillates up and down. However, Rh is low in the dry season and rises in the rainy season. It is also observed that T, Rh and N decrease with atmospheric level.

From the statistic and ANOVA table (Table 1), poor correlation between N and T shows that linear regression cannot be used to predict the dependent parameter. In the case of N and Rh, where good correlation exists, linear regression can be used to predict the dependent parameter. This shows that variability of N is majorly anchored on Rh parameter.

Conflict of Interests

The author has not declared any conflict of interests.

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