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Scaled-up Analysis of Surface Refractivity across West Africa

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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Short Research Article

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ABSTRACT

The scaled-up analysis of surface refractivity over a period of 22 years (1983 – 2005) for different climatic zones in West Africa was calculated using the results of surface refractivity at 2 m, and 10 m averaged monthly and annually. The annual surface refractivity normalised value is 0.91 for Z2/Z1, 0.97 for Z3/Z1, and 0.94 for Z4/Z1 at 2 m while the normalised value of surface refractivity is 1.00 for Z2/Z1, 0.98 for Z3/Z1, and 0.96 for Z4/Z1 at 10 m. At 10 m, the value is relatively constant. The monthly variation shows that surface refractivity reduced as latitude increases in West Africa except in wet months for climatic zone 3 at 2 m and wet months in climatic zone 2 at 10 m. The wet months had a characteristic of reduction in normalised surface refractivity value with most severe reduction within latitudes 10°N and 15°N. This decrease in refractivity across the latitude translates into an increase in the velocity of terrestrial propagation across the latitude, resulting in excessive bending of electromagnetic waves toward the earth's surface, along curves with radii less than the radius of the earth.

Keywords: Climatic zones; normalised surface refractivity; radio propagation; West African latitudes.

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1. INTRODUCTION

The direct radio refractivity measurement usinofg radio sounding and refractometer can only give a rough idea of the refractivity distribution [1]. The basic disadvantage of the radiosonde is that it was not able to provide a detailed idea of temporal refractivity structure. Due to lack of direct measurements of surface refractivity for different climatic zone across West Africa, the field processing methods representing indirect methods of refractivity structure sounding have turned out to be a suitable alternative to direct means of measurement [2]. The scaled-up analysis of surface refractivity over a period 1983 – 2005 for different climatic zones in West Africa was calculated using the results of surface refractivity at 2 m and 10 m averaged monthly and annually. The scale-up factor is the degree of reduction or enlargement of surface refractivity with respect to a reference value. The scale-up factor gives a model measurement when the scale factor is less than 1, it indicates a reduction and when it is greater than 1; it indicates an increase.

2. THEORETICAL BACKGROUND

The surface refractivity of air is a function of pressure, temperature and relative humidity. In the studies of refractivity, all the three parameters can be combined into one single parameter that facilitates the analysis and studies some of the effects of meteorological factors on radio wave propagation at the higher frequencies like microwaves [3]. Radio waves travel through a vacuum with a speed equal to the speed of light. In any other medium, the speed of the radio waves will be a ratio of the speed of light in a vacuum (c) and the refractive index (n) of the medium [4]. The value of ‘n’ for dry air is almost the same for radio waves and the light waves. But the ‘n’ of water vapour, which is always present in some quantity in the lower troposphere, is different for the light waves and radio waves [5]. This arises from the fact that water vapour molecule has a permanent dipole moment which has different responses to the electric forces of different frequencies and at microwave frequencies water vapour molecules are subjected to electronic polarisation [6].

3. MATERIALS AND METHODS

The dielectric constant and the refractive index of water vapour is greater than that of dry air. The refractive index ‘n’ for moist air near the surface has the value of the order of 1.0003 and the variation in ‘n’ is only of the order of 10^4. The surface refractivity, N, is defined in terms of ‘n’ [4] as:

$$N = (n - 1) \times 10^6 \quad (1.0)$$

This enables the easy manipulation of SRI which is of the order of 300 rather than ‘n’ which is an inconvenient number. A theory based on the molecular polarisation of the gases of the atmosphere enables the refractivity to be related to the temperature T in °K, to atmospheric pressure P in millibars and to water vapour pressure, e in millibars. The surface refractivity, N is expressed by the well-known relation [4]:

$$N = \frac{77.6}{T}\left[P + 4180\frac{e}{T}\right] \quad (2.0)$$

In terms of measured meteorological quantities, surface refractivity, N can be expressed as [4]:

$$N = 77.6\frac{P}{T} + 3.73 \times 10^5\frac{e}{T^2} \quad (3.0)$$

where: P = Atmospheric Pressure (hPa), e = water vapour pressure (hPa) and T = Absolute Temperature (K). Therefore, N is expressed as:

$$N = \frac{77.6}{T}\left[P + 4180\frac{e_s RH}{T}\right] \quad (4.0)$$

where e_s is the saturation vapour pressure in millibars and RH is the relative humidity in percent.

The expression for the surface refractivity, N, may be regarded to consist of the dry term and wet term. The dry term does not depend on humidity; it is proportional to the density of the air. The dry term is also referred to as pressure term. The wet term depends on moisture variation and it is responsible for the temporal and spatial variability of surface refractivity. The dry term decreases with an increase in temperature at constant pressure. The wet term increases with increase in relative humidity [7].

4. RESULTS AND DISCUSSION

4.1 Spatial Variation of Surface Refractivity across West Africa

In this work, West Africa continental area was partitioned into four climatic zones across the latitudes – zone 1 (Lat < 5°N); zone 2 (5°N ≤ Lat < 10°N); zone 3 (10°N ≤ Lat < 15°N) and zone 4 (Lat ≥ 15°N). Raw point datasets for 22 years (1983 – 2005) including air temperature, relative humidity and atmospheric pressure at 2 m and 10 m, averaged daily with attributes of geographic features (longitude and latitude), were extracted from NASA meteorological databank through Notepad basic text editor using text import wizard to delimit the general data format into numeric values and number. The data were assembled together in an attribute table created on the Microsoft Excel spread sheet. Data covering thirty-six meteorological stations in four climatic zones across West Africa within Latitude 3°N and 20°N were used for the study.

Figs. 1 and 2 show the spatial variation of surface refractivity estimated from satellite dataset. The seasonal variation of surface refractivity at 2 m (1983 – 2005) in climatic zones 1 and 2 showed a similarity of bimodal pattern with maximum surface refractivity values of 326 N-Units and 300 N-Units respectively in April. During this month, the humid maritime air mass has extended its influence up to 10°N resulting in heavy rainfall and a slight decrease in temperature. The least values of 300 N-Units and 261 N-units were observed in January when the coverage of dry continental air is at the farthest southern location, covering entire West Africa; humidity is very low, most especially in zone 2 where there is no influence of coastal breeze with characteristic high temperature.

In climatic zones 3 and 4, seasonal variations of surface refractivity followed the similar mono-modal trend. The values of SRI were also influenced by the intensity of rainfall. The maximum values of surface refractivity recorded in zone 3 and 4 were 332 N-Units and 336 N-Units in June/July respectively while the minimum values in zone 3 and 4 were 272 N-Units and 269 N-Units in December/January respectively.

The climatic zones 1 to 4 had a range of 6 N-Units to 9 N-Units within the period of 1983 - 2005, zone 1 had the mean and standard deviation of 313±5 N-Units, zone 2 had 286±3 N-Units, zone 3 had 304±4 N-Units, and zone 4 had 293±4 N-Units.

In Fig. 2, the seasonal variation of surface refractivity at different climatic zones across West Africa was plotted. At 10 m, in zones 1 and 2, surface refractivity had a marginal seasonal range of 4 – 8 N-Units while zones 3 and 4 had a seasonal range of 10 – 13 N-Units. The marginal range in seasonal variation at 10 m, unlike at 2 m, was caused by remoteness in height to evaporation sources and moisture transport associated with both surface sensible heating and atmospheric latent heating.

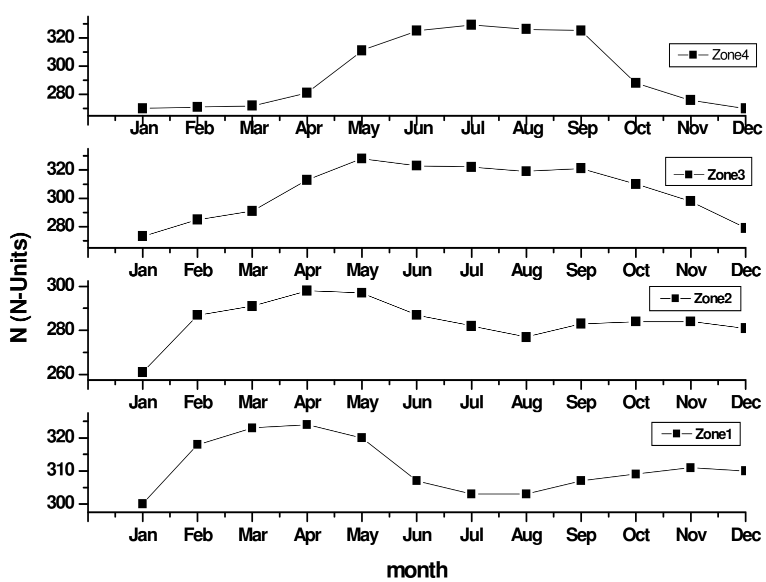

Fig. 1. Seasonal variation of Surface Refractivity (N) at 2 m for different climatic zones across West Africa (1983 – 2005)

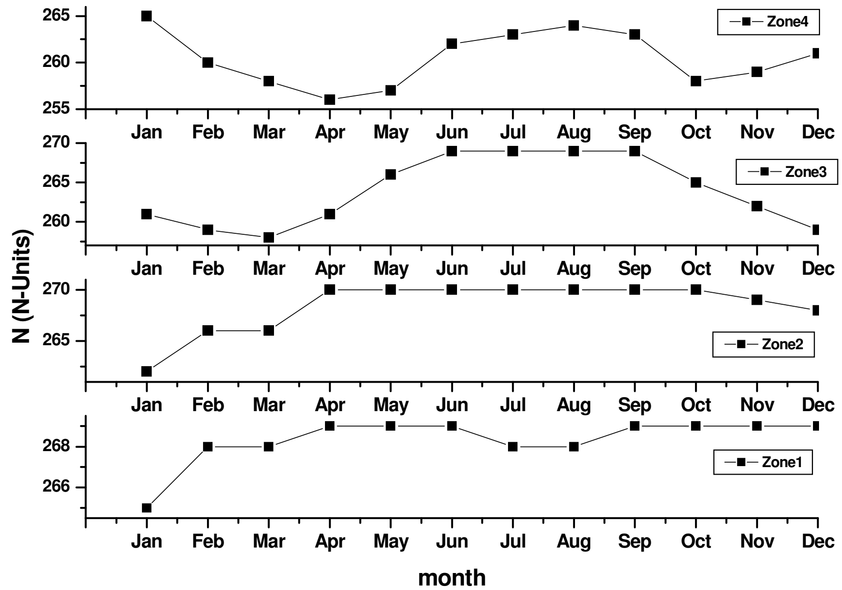

Fig. 2. Seasonal variation of Surface Refractivity (N) at 10 m for different climatic zones across West Africa (1983 – 2005)

5. RELATIVE COMPARISON OF SURFACE REFRACTIVITY ACROSS WEST AFRICA

The scaled –up values of monthly and annual averages of surface refractivity for different climatic zones at 2 m and 10 m are shown in Figs. 3-6. The surface refractivity value in climatic zone 1 was used as the benchmark for refractivity phenomenon to deduce the scaled-up factor across West Africa for different climatic zones.

When it is greater than 1, it indicates enlargement. The monthly normalised value of surface refractivity at 2 m is 0.91 for Z2/Z1, 0.98 for Z3/Z1, and 0.85 for Z4/Z1. At 10 m, normalised value of surface refractivity is 0.99 for Z2/Z1, 0.98 for Z3/Z1, and 0.97 for Z4/Z1. The monthly variation shows that surface refractivity reduced as latitude increases in West Africa except in wet months for climatic zone 3 at 2 m and wet months in climatic zone 2 at 10 m. The annual surface refractivity normalised value is 0.91 for Z2/Z1, 0.97 for Z3/Z1, and 0.94 for Z4/Z1 at 2 m while the normalised value of surface refractivity is 1.00 for Z2/Z1, 0.98 for Z3/Z1, and 0.96 for Z4/Z1 at 10 m. At 10 m, the value is relatively constant.

The scale-up values of surface refractivity with respect to other climatic zones are shown in Table 1. Higher elevations in climatic zones 2 and higher latitudes in climatic zone 4 were peculiar features responsible for high values of pressure in the climatic zones. Temperature increases from climatic zone 1 to 4 due to a decrease in cloud cover phenomenon across the latitudes which allows more intense surface heating thereby raising the temperature of air close to the surface. Relative humidity decreases across the latitudes from zone 1 to 4; this is due to the rainfall distribution across the latitude as determined by the seasonal movement of Inter – Tropical Discontinuity (ITD) over West Africa. The variation of pressure across the latitudes over West Africa is negligibly small and therefore, it does not have a significant effect in the seasonal variation of surface refractivity across West Africa.

The temporal and spatial variations of surface refractivity are determined by temperature and relative humidity distributions for different climatic zones. In Fig. 7, the temperature increased across the latitude in wet months but it decreased in dry months. This was influenced by north-south solar radiation activity which determines the seasonal maximum possible sunshine hour across West Africa. Temperature variation across the latitudes over West Africa is inversely proportional to relative humidity variations. In zone 1, average temperature and relative humidity were 25℃ and 95%; zone 2 was 27℃ and 82%; zone 3 was 30℃ and 50%; and zone 4 was 33℃ and 26%.

The change in relative humidity over West Africa is most significant of all the 3 variables involved in the estimation of surface refractivity and is, therefore, the first primary cause of variation in a spatial and temporal variation of surface refractivity. Adediji [8] endorsed that higher values of surface refractivity and reduced to sea level value refractivity were observed for Nsukka, in South-eastern Nigeria and Akure, in South-western Nigeria.

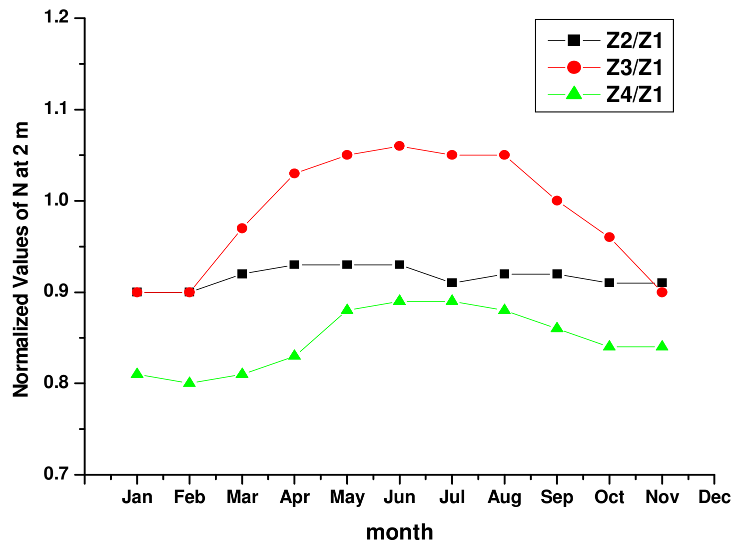

Fig. 3. Monthly averaged normalised values of surface refractivity index at 2 m across different climatic zones in West Africa (1983 – 2005)

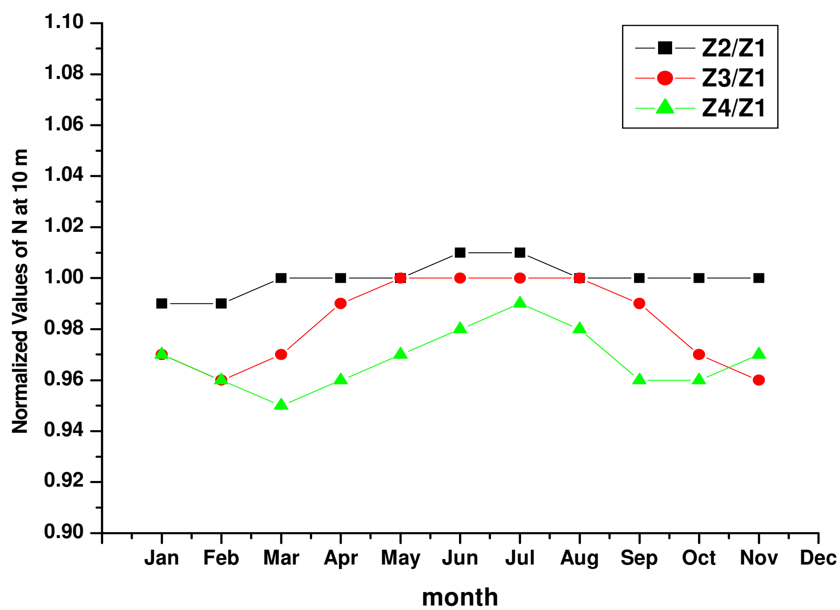

Fig. 4. Monthly averaged normalised values of surface refractivity index at 10 m across different climatic zones in West Africa (1983 – 2005)

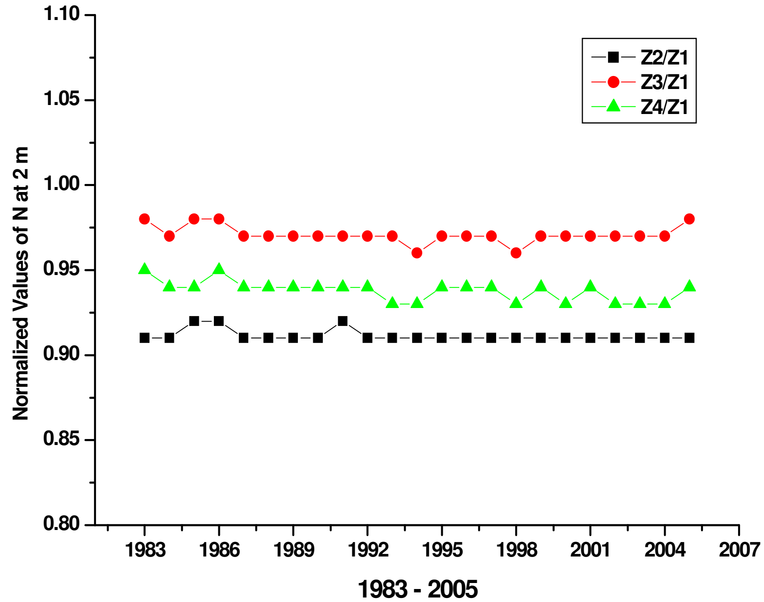

Fig. 5. Annual averaged normalised values of surface refractivity index at 2 m across different climatic zones in West Africa (1983 – 2005)

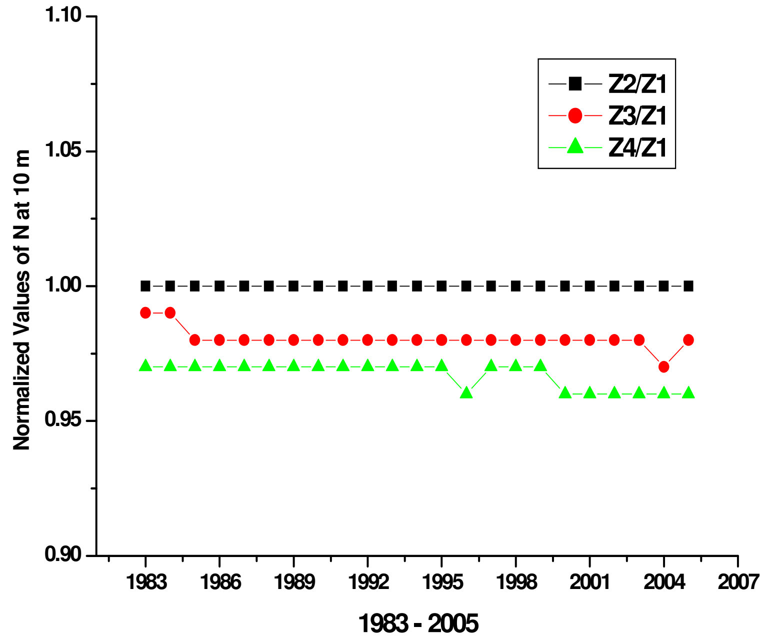

Fig. 6. Annual averaged normalised values of surface refractivity index at 10 m across different climatic zones in West Africa (1983 – 2005)

The relative comparison of surface refractivity values in dry term is close to unity across West Africa while the wet term shows a significant decrease in value as latitude increases [9]. The results in Table 1 show that the combined change in pressure and temperature in the dry term across West Africa was not significant enough to bring about major variation in surface refractivity values across the different climatic zones. However, the combined change in temperature and relative humidity was very considerable, this was the basis for the climate classification, and the reason for the unique refractivity characteristic in each zone across West Africa.

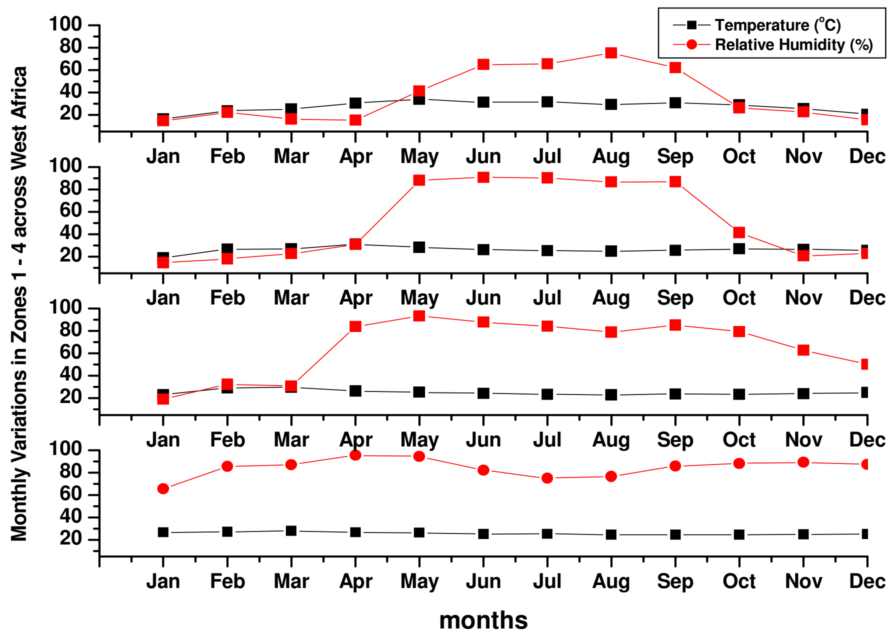

Fig. 7. Seasonal variation of temperature and relative humidity in different climatic zones across West Africa

Table 1. Averaged normalised values of surface refractivity index for West Africa (1983 – 2005)

Ratio	Scaled-up N	
	Dry Term	Wet Term
Z2/Z1	0.99	1.01
Z3/Z1	0.99	0.78
Z4/Z1	0.99	0.52
Z3/Z2	0.99	0.77
Z4/Z2	0.99	0.51
Z4/Z3	1.00	0.66

6. CONCLUSION

The implications of normalised values of surface refractivity across West African climatic zones is very significant to radio propagations [10,11]. The trends of surface refractivity from climatic zones 1 – 4 depicted by normalised values showed some increment across the latitude most especially in dry months. The wet months had a characteristic of reduction in normalised surface refractivity value with most severe reduction within latitudes 10°N and 15°N. This decrease in refractivity with latitude translates into an increase in the velocity of terrestrial propagation across the latitude, resulting in excessive bending of electromagnetic waves toward the earth's surface, along curves with radii less than the radius of the earth. The degree of climate dryness across the latitude was portrayed by a reduction in normalised surface refractivity while the degree of wetness was showed by enlarged normalised values of surface refractivity.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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