American Journal of Astronomy and Astrophysics
2018; 6(4): 97-101
http://www.sciencepublishinggroup.com/j/ajaa
doi: 10.11648/j.ajaa.20180604.11
ISSN: 2376-4678 (Print); ISSN: 2376-4686 (Online)

Anomalous Radio Propagation and Relative Incidence inTropical Zone

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To cite this article:
Adedayo Kayode David, Emmanuel Israel, Ojo Olusola Samuel. Anomalous Radio Propagation and Relative Incidence inTropical Zone. *American Journal of Astronomy and Astrophysics*. Vol. 6, No. 4, 2018, pp. 97-101. doi: 10.11648/j.ajaa.20180604.11

Received: January 16, 2019; **Accepted**: March 5, 2019; **Published**: March 22, 2019

Abstract: This paper investigate the percentage of anomalous occurrence in tropic region of West Africa using meteorological data obtained from Era interim archive. The data covered the period of 36 years span from 1979 to 2014. Refractivity gradient, G are calculated from meteorological parameters (temperature, relative humidity and pressure) via surface refractivity and refractivity at 100m above the sea level. Relative incidence, $\beta_{o,}$ which percentage of time refractivity gradient at 100 m is less than -100 N-units/km were estimated from cumulative distribution of refractivity gradient. The result shows the occurrence of seasonal variation of refractivity gradient across the observed stations with high variability in Jos. Super refraction and ducting condition are prevalent in Akure and Lagos stations, whereas sub refraction and ducting conditions are predominant in Jos during the rainy and dry season respectively. Minimum values of relative incidence of about 10% and 78% at Akure and Lagos respectively were obtained around 12 noon. Highest relative incidence of 80%, 98% and 97% were obtained at Jos, Lagos and Akure respectively in the mid night. Positive correlation of 0.29 and 0.66 exist between surface refractivity and β_o in Lagos and Akure respectively, moreover negative correlation of -0.84 is observed in Jos.

Keywords: Anomalous, Propagation, Gradient

1. Introduction

Anomalous propagation conditions can have a significant impact on radio wave propagation resulting to multipath fading and signal outage [1]. These conditions arises in troposphere due to nonstandard variation of vertical refractivity through different layer of the atmosphere [2]. Refractivity variation depend on the physical structure of the atmosphere which anchor on meteorological conditions. This, however necessary in designing a wireless communication system.

In this study refractivity gradient, G, in the lowest 100 m of the atmosphere was estimated and used to construct cumulative distribution. β_o statistics for Akure, Lagos and Jos stations in Nigeria were derived from the cumulative distributions of the vertical refractivity gradient. Seasonal distributions of refractivity gradient and β_o variations are presented. Refractivity and refractivity gradient have earlier been examined across some selected locations in Nigeria by many researcher [3-8]. However, important of β_o in investigating of nonstandard propagation have not been dealt with.

Study Locations

Akure is situated in southwestern Nigeria along the tropic rainforest zone. It is located in 7.25° N latitude and 5.02° E longitude, with an altitude of 353 m above the sea level. The climate is hot and humid, influenced by rain-bearing southwest monsoon winds from the ocean and dry northwest winds from the Sahara Desert. The rainy season lasts from April to October, with rainfall of about 1524mm per year. Temperatures vary from 28°C to 31°C with mean annual relative humidity of about 80%. Lagos is also a southwestern city in tropic region of Nigeria located in 6.6° N latitude and 3.3° E longitude, with 39 m above the sea level. It has similar climatic variation with Akure, however, as the city is located near the equator, the temperature remains constant with no significant difference between the hottest month and the coolest month. The hottest month is March with average temperature 28.5°C, while the coolest month is August-September with average temperature 25°C [9]. Jos is located on the Jos Plateau at an altitude of about 1,238 meters above the sea level. Situated almost at the geographical center of Nigeria with latitude 9.89° N and longitude 8.85° E. Jos enjoys a more temperate climate than much of the rest of Nigeria. Average monthly temperatures range from 21–25°C, and from mid-November to late January, night-time temperatures drop as low as 11°C. Hail sometimes falls during the rainy season because of the cooler temperatures at high altitudes. Jos receives about 1,400 millimetres of rainfall annually, the precipitation arising from both conventional and orographic sources, owing to the location of the city on the Jos Plateau.

2. Data Acquisition and Analysis

2.1. Data Acquisition

Meteorological data (Temperature, Relative humidity and pressure) from European Centre for Medium-Range Weather Forecasts (ECMWF) Era interim was used for this analysis. ERA-Interim is produced at T255 spectral resolution (about 80 km) and covers the period from January 1979 to present, with product updates at approximately one month delay from real-time. The time resolution of the products used 6 hours per day (00 UTC, 06 UTC, 12 UTC and 18 UTC).

2.2. Data Analysis

2.2.1. Anomalous Propagation

Surface refractivity, N_s and refractivity at height 100 m altitude above the ground, N_1, needed to calculate refractivity gradient G was obtained from meteorological parameters using equation (1) [10].

$$N = 77.6\frac{P}{T} + 3.73\times10^5\frac{e}{T^2} \tag{1}$$

where P is pressure (hPa), T is temperature (K), e is water vapour pressure (hPa) at corresponding levels. Water vapour pressure, e, was obtained using equation (2):

$$e_s = 0.0611H\times\exp\left(\frac{17.502t}{t+240.97}\right)$$

where e_s is saturated water vapour (hPa), H is relative humidity (%) and tis temperature (°C).

Refractivity gradient G, which determined anomalous conditions of radio wave propagation was obtained from equation (3) [11]:

$$G = \frac{N_s - N_1}{h_s - h_1} \text{ (N-units/km)} \tag{3}$$

where h_s and h_1 represent surface height and height corresponding to N_1 respectively. Anomalous propagation also known as non-standard propagation causes radio signal to bend downwards to the Earth surface (super refraction and ducting, G < -100) in a way different from the standard. This leads to highly variable propagation conditions and significantly affects radio communications links and radar performance [12]. Anomalous propagation can be obtained from refractivity gradient, when G < -100. Refractivity conditions is shown in table 1.

Table 1. *Refractivity Propagation Conditions.*

Refractivity Conditions	G (N-units/km)
Sub Refraction	> 0
Standard	G = -40
Super Refraction	-40 > G >-157
Ducting	G < -157

2.2.2. β_o Factor Deduction

β_o factor is defined as the percentage of time that the refractivity gradient in the lowest 100 m above the ground is less than -100 N-units/km. It play vital role in investigating clear air propagation and interference, and it is used to show the relative frequency of anomalous propagation. β_o is obtained from G statistics in the lowest 100 m of the atmosphere. It has been discovered that β_o can be used with reasonable accuracy to represent the presence of ducting. It was also established in [10, 13] that β_o correlated to the latitude of the area under consideration, showing higher values in equatorial regions and lower toward the poles.

3. Result Analysis

3.1. Refractivity Gradient and Anomalous Propagation

Figure 1, depict the average seasonal variations of G over the whole periods of study. Values of G oscillate between -660 and 138 N-units/km, with a range of 798 units in Jos. In Lagos (coastal area), it varies from -390 to -222 N–units/km, with a range of 168 units, whereas in Akure, it fluctuate between -325 and -125 N-units/km. The values of the gradient are more negative (lower) in dry months of November – March, than rainy months of April – October in all the observed locations.

Table 2. *Percentage Occurrence of Anomalous Propagation.*

	Lagos			Akure			Jos		
	Ducting	Super Ref.	Sub Ref.	Ducting	Super Ref.	Sub Ref.	Ducting	Super Ref.	Sub Ref.
Jan	100	0	0	93	7	0	98	1	0
Feb	100	0	0	94	6	0	99	1	0
Mar	100	0	0	96	0	0	98	0	0
Apr	100	0	0	87	11	1	82	12	5
May	99	1	0	81	19	0	53	34	8
Jun	96	4	0	62	35	1	26	34	22
Jul	98	2	0	50	46	0	4	39	38
Aug	93	7	0	57	36	1	1	31	51
Sep	93	7	0	44	49	1	3	43	34

	Lagos			Akure			Jos		
	Ducting	Super Ref.	Sub Ref.	Ducting	Super Ref.	Sub Ref.	Ducting	Super Ref.	Sub Ref.
Oct	99	1	0	58	39	1	41	38	10
Nov	100	0	0	86	13	0	96	4	0
Dec	100	0	0	94	6	0	99	1	0
Annual	98	2	0	75	22	0	58	20	14

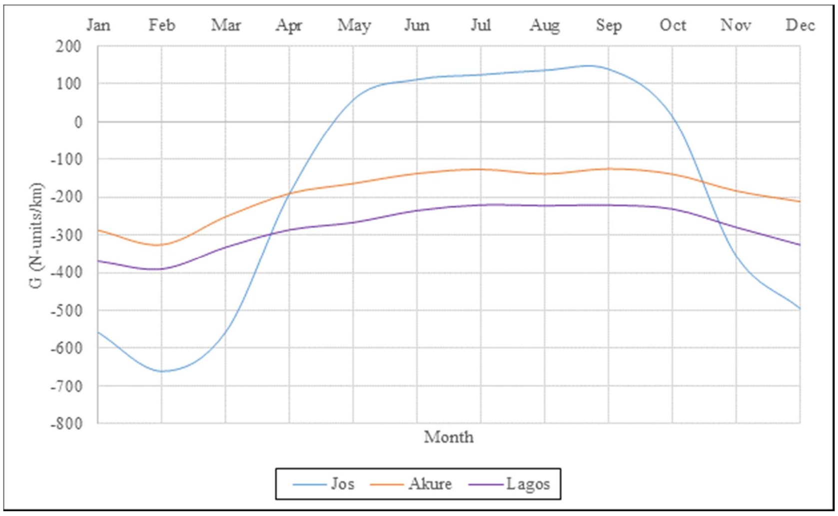

Figure 1. *Mean monthly variation of the refractivity gradient, G, at 100 m (1979 -2014).*

The variation is higher in Jos than other observed locations. This may be attributed to the reduction in amount of water vapour content in the atmosphere in the dry season [6, 14]. The observed trend in G across the locations, however indicate the occurrence of super refraction and ducting in coastal area, since all months mean of G in this region comprises of Lagos and Akure does not exceed -100 N-units/km. The trend of G in Jos indicate, the occurrence of ducting in dry months and sub refractive in rainy months. Percentage occurrence of anomalous propagation is shown Table 2. In coastal region (Lagos and Akure), ducting occurrence is more frequent throughout the year, this may be attributed to the marine boundary layer (MBL), which forms as air flows from warm land to cooler sea, thus becoming a marine internal boundary layer (MIBL).

Coastal morphology, land-sea temperature contrast, sea surface temperature, orography, the ambient wind and mesoscale structures such as the land-sea breeze circulation control and dictate the characteristics of MIBL and associated ducts [15].

However, ducting occurrence was high during the dry months of November –May in Jos (inland Plateau area), and very low in the rainy months of June-October. Noticeable sub refraction occurrence was obtained in this location during the rainy season. The presence of ducts here may be as a result of dry, convective boundary layers. This result implies that radio wave signals may be guided by the earth's surface or by other layers of grossly different index of refraction.

3.2. Hourly and Monthly Distribution of βo Parameters

Hourly and monthly variations of βo parameters have been derived from cumulative distributions of G at lowest 100 m altitude. Figure 2 represent the hourly variation of β_o. The values of β_o obtained in Lagos, Akure and Jos at 00 hour of local time is 100, 98 and 79% respectively.

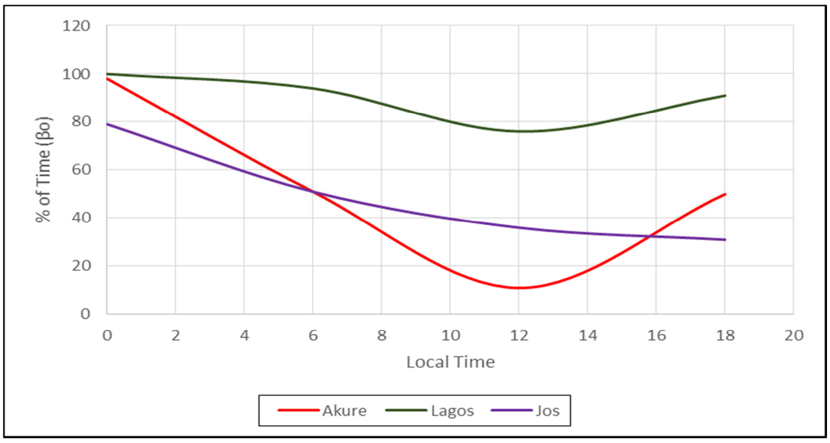

Figure 2. *Hourly distribution of β_o factor.*

Minimum values of 76 and 11% are obtained at 12 noon in Lagos and Akure respectively. Whereas, minimum of 31% is obtained in Jos at 18 hours. This imply that higher percentage of ducting is associated to mid-night and early morning. Figure 3 shows the seasonal variation of β_o in the three locations. The long –term value of β_o in Lagos varies between 72 and 67% throughout the year, indicating the percentage of occurrence of super refractive and ducting. β_o value in Akure have similar trend as that of Lagos, it oscillate between 69 and 42%. Reverse is the trend in Jos, as the seasonal values of βo oscillate between 96 and 10%, with maximum in dry season.

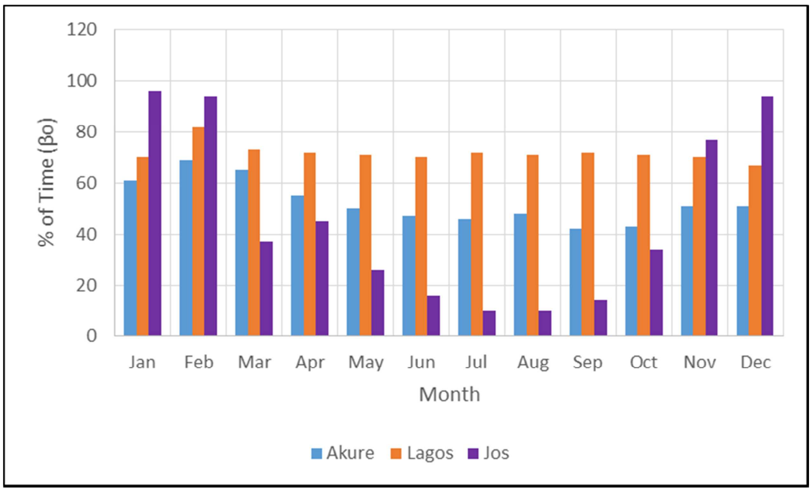

Figure 3. *Monthly variation of β_o factor across Nigeria.*

3.3. Correlation of Surface Refractivity with βo

Table 3 shows statistics of surface refractivity along with β_o parameters. Mean, maximum, minimum of surface refractivity and β_o with correlation between surface refractivity and β_o, r, are estimated.

Table 3. *Statistic of surface refractivity and β_o parameter.*

Stations	$\overline{N}$	N_{max}	N_{min}	*Bo*	βo_{max}	βo_{min}	*r*
Lagos	399	407	390	71	82	67	0.29
Akure	395	403	387	52	69	42	0.66
Jos	372	387	352	46	96	10	-0.84

Positive correlation of 0.29 and 0.66 exist between surface refractivity and βo at Lagos and Akure stations respectively. Negative correlation of -0.84 is obtained in Jos. This result shows significant relationship between surface refractivity and β_o.

4. Conclusion

Using reanalysis data, refractivity gradient and β_o factor have been estimated and analysed across three locations in Nigeria. β_o parameters, which indicate the percentage of anomalous propagation has been calculated for Lagos, Akure and Jos. Refractivity gradient experience seasonal trend across the three locations with high variability in Jos. High percentage of β_o statistics is observed at midnight with local time of 00 hours across the stations. Super refraction and ducting conditions are prominent in Akure and Lagos. This may be attributed to high temperature inversion due to land and sea breeze in this part of the country. This imply that radio wave propagate in these locations will may be trapped. In other hand, sub refractive conditions which may cause diffraction loss is predominant during the rainy season in Jos, whereas ducting phenomenon is common in the dry season. Positive correlation of 0.29 and 0.66 exist between surface refractivity and βo in Lagos and Akure respectively, moreover negative correlation of -0.84 is observed in Jos.

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