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Radio Duct Estimation in Some Selected Areas of the Gulf of Guinean Troposphere

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Abstract

The regular occurrence of strong duct entrapment layers is prevalent in coastal areas of the Gulf of Guinea region where it is evident that they occur frequently and their probability of occurrence poses enough operational effects on current radio communication signals. In this work ducting model was used to predict the presence of duct phenomena in the Gulf of Guinea region. Also, Advanced Refractive Effects Prediction System (AREPS) was used to compute refractivity using radiosonde data from Abidjan, Douala and Libreville for the years 2000 to 2003, 2008, 2009 and 2011, 2014, respectively. Results show that Abidjan, Douala and Libreville have altitudes where pronounced ducting phenomenon occurred majorly to be within the first 300m, 180m and 160m above sea level. Abidjan and Douala troposphere exhibited more presence of surface duct with 85.2% and 75.4% occurrences and surface-based duct with 26.2% and 45.6% occurrences. Libreville with surface and surface based duct has 34.5% and 10.1% occurrences. The outcome of study is expected to be of great benefit to telecom-industry and military formations in West Africa sub- region and beyond.

1. Introduction

Various researches have shown that the troposphere is a region experiencing varying degree of anomalous propagation of radio waves owing to its associated varying climatic conditions. Advection, surface spreading, evaporation, dissolution, sedimentation, emulsification, photo-oxidation, and biodegradation [1] are processes that affect the weather conditions by altering the temperature and humidity of the atmosphere of the region air which is moved about, mixed up and elevated by tropical storms and anti-cyclones [2]. These vertical changes in tropospheric characteristics have substantial impact on the propagation of radio waves [3,4].

The presence of tropospheric ducts leads to various effect on the radio-wave propagation, such as trapping, deep slow fading, strong signal enhancement and multipath fading [5]. Radio waves that propagates through the atmosphere have shown to have remarkable behaviours as they encounter varying meteorological conditions [6]. The effects of radio ducting are important in a variety of applications. Ducting can greatly modify the effective range of radio communications and navigation radar used by ship and aircraft and can lead to high erroneous conclusions if not properly accounted for in the interpretation of weather radar signals [7,8], and weather dependent communication/measuring instruments. Trapping of energy within the duct causes a corresponding decrease in energy on the other side of the trapping layer, resulting in poor radio communications and holes in the radar cover. An elevated duct is a duct that has its lower limit above the ground level. In other scenarios, a surface duct has its lower limit is on the ground or the lower limit of the associated ducting layer can, however be above the ground [9] called surface-based duct. Duct delineation is determined by several meteorological conditions.

One other major concern of the side effect of radio ducting is in prospect of lost communication between transceivers or system payloads and the operators. The risk of ploughing into airliners, cargo planes and helicopters that fly at low altitude during moment of signal loss or distortion has not dissuaded the crave for their use for either civilian purposes or military interventions. This is evident in the demand by tornado researchers to send them into storms to gather data or the energy companies wanting to use them to monitor pipelines leakages and vandals. Also, are the law-enforcement agencies as in Police and Road Safety Marshalls hopping to send them to capture images of speeding cars' license plates or track fleeing suspects, monitor traffic situations on the roads and for border patrol with neighbouring countries, and along coastlines for spotting smugglers and illegal aliens.

The Gulf Coast of Guinea is a region of the coast of Atlantic Ocean, Western Africa. The Gulf coast line extends from Liberia through Cote D`Ivoire, Ghana, Togo, Benin, Nigeria, Cameroun, Equatorial Guinean, Gabon and Republic of Congo to the Democratic Republic of Congo. Generally, the Gulf Coast of Guinea exhibits climatic conditions with some level of variations which by extension manifest severally along locations in the span of the Gulf coast. This is the reason why meteorological observation must be accurately carried out at points widely separated in the vertical and horizontal directions over a long period of time. The Nigeria, Ivory Coast, Cameroun and Gabon coastlines are approximately 853 km, 515 km, 402 km and 885 km respectively; all facing the Atlantic Ocean. This is indeed a sizeable land mass beguiled with massive atmospheric irregularities which make preliminary assessment of radiowave propagation in these regions difficult and subject to significant impairments [10].

[11] used radiosonde data and employed monthly means, standard deviations and harmonic analysis for their study. [12] used ANN to predict duct presence with radiosonde data obtained from Helliniko airport, Athens Greece for their study. [13], [14], [7], [15], [16], [4] and [17] all used measurements campaign for their data capture but employed various models such as statistical distributions of the refractivity, New Path Loss Model (NPLM), Semi- empirical model, Parabolic Equation (PE) method and other known models as stated in their works. However, one unique failure that commonly cuts across most research in this area is the absence of the use of daily averages for their analysis. This study seeks to improve on this anomaly and use daily averages over four (4) and two (2) years period.

Owing to the complexity and reliability of communication signals to human use, the need to have an accurate assessment of the propagation environment in particular, the Gulf Coast of Guinea, allows for these effects to be taken into account and resources deployed to their best effect. However, research results have shown that optimised planning of radio services in the Gulf of Guinea requires data which take account of the specific climatic conditions. Long period of meteorological data are needed for such study and these data are never obsolete for use owing to its ability to reveal salient attributes of the scenarios under review.

2. Methodology

2.1 Data Acquisition and Sample Size

Abidjan, Douala and Libreville were analysed for a complete representation of the Gulf coast of Guinea. The distribution of sites is to give a wide geographical coverage and appropriate description of the needed information. Also, quality controlled radiosonde data of 65578 DIAP Abidjan observation station at 12Z (5.25^0 N, 3.93^0 W), 64910 FKKD Douala observation station at 12Z (4^0 N, 9.7^0 E) and 64500 FOOL Libreville observation station at 12Z (0.45^0 N, 9^0 E) obtained from the University of Wyoming, College of Engineering, Department of Atmospheric Science USA web site which came from observations made with radio balloons launched thrice daily (at 00, 09 and 12

LT) were used. The datasets cover the periods 2000, 2003, 2007, 2009, 2011, 2014 and 2021 (Table 1) respectively, and the radiosonde parameters considered were the temperature, relative humidity, pressure and height. Analysed meteorological data spanned a maximum height of 1000m (1 km) above the ground.

Table 1: List of Stations, Years and Months Considered

Stations	Years	Months
Abidjan	2000	January – December
	2001	January, February, March, April, May and June
	2008	January – December, except April
	2009	January – December
	2014	January – December
	2021	January - November
Douala	2009	January – December, except September
	2011	January – December
Libreville	2000	January – December, except April
	2001	January – December
	2002	January – December
	2003	January – December

2.2 Characterisation of in-situ environment and data set

For the purpose of clarity and understanding the base of the lower layer of the troposphere (near surface) is considered in this work as between the minimum station level (8m) and a vertical height of 300m. The upper layer of the troposphere is considered as between vertical height of 300m and 1000m above sea level.

For the Abidjan, Douala and Libreville, available in-situ data were carefully sorted to highlight readings of temperature, pressure, humidity and their corresponding heights ranging from respective station level heights of 8m, 15m and 15m to 1000 metres above sea level. These values were entered in the Custom Column and View Refractive Summary of the Environment Creator in AREPS programme to compute the *M*-Unit, *N*-Unit and display the type of Layer (Traping, Superrefraction, Subrefraction, etc).

For each location and for each year, from January to December, these daily sorted data were carefully processed by avoiding wrong entries one after the other. Importantly, in this work, three days within the months were selected to represent each month, and each year is divided along quarterly symmetry in order to aid discussion and comprehension. The choice for the three days selection is to ensure uniformity in the average daily datasets used in each month and some months have no complete radiosonde data.

The refractivity profile is characterised by the properties indicated in Figures 1, and are defined by the following parameters; duct height *H*, duct layer thickness ΔH, duct intensity ΔM and negative gradient of refractivity in the inversion layer α_d. With the Earth radius being 6370 km, we have;

$$M(h) = N(h) + 157h \text{ with } h \text{ in km} \quad (1)$$

Where *M(h)* is the modulus of refractivity and *N(h)* is the refractivity at height *h* above sea level. Under normal conditions of propagation *M* increases with height but decreases with height only if *dM/dh* is lower than –157 N-units/km, that is, within ducting layers. The *ducting model* consists of a three part linear refractivity profile shown in Figure 1 and is related by the algebraic manipulation of the parameters of the *N* to those of the *M* and vice versa [2,23].

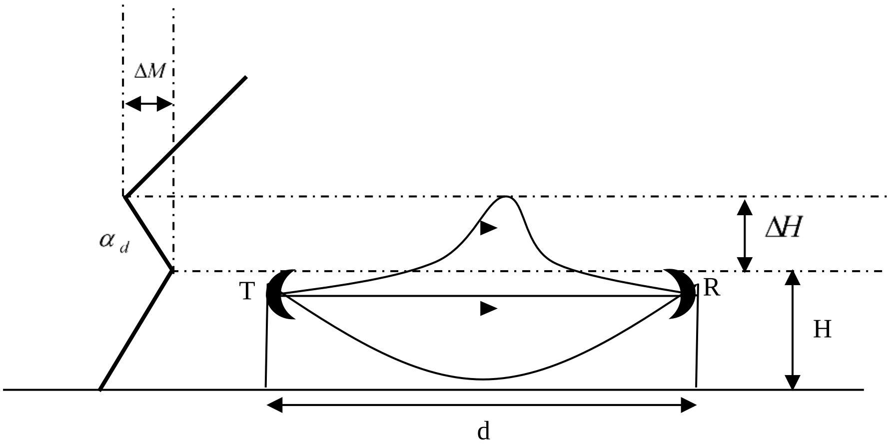

Figure 1: Schematic Description of Ducting phenomenon with Transmitter (T), Distance (d), Receiver (R)

3. Results and Discussion

Radio duct occurrence probability is defined as the percentage of time that gradient of the refractive modulus, *M*(h), is less than 0 MU/km, or the modulus refractivity gradient α (*dM/dh*) is less than -157 NU/km [18].

3.1 Occurrence Probability of Ducting Events

For the six years consideration of Abidjan scenario, the maximum frequency of duct occurrence is 36. Its average value is 30.3. For the two years consideration of Douala, maximum duct occurrence is 38 with an average value of 27 and for the four year consideration of Libreville, the maximum value is 13 with an average value of 11.3 (Table 2). Considering the total number of radio duct occurrences at the three stations over the given periods, duct occurrence number at Abidjan, situated in the lowest altitude tends to be considerably larger than those at the higher altitude such as Douala and Libreville.

Table 2: Ducting Occurrences in the Selected Stations

Station	Year								
	2000	**2001**	**2002**	**2003**	**2008**	**2009**	**2011**	**2014**	**2021**
Abidjan	34	21	*-	*-	28	35	*-	33	36
Douala	*-	*-	*-	*-	*-	16	38	*-	*-
Libreville	10	13	10	12	*-	*-	*-	*-	*-

*- No radiosonde data

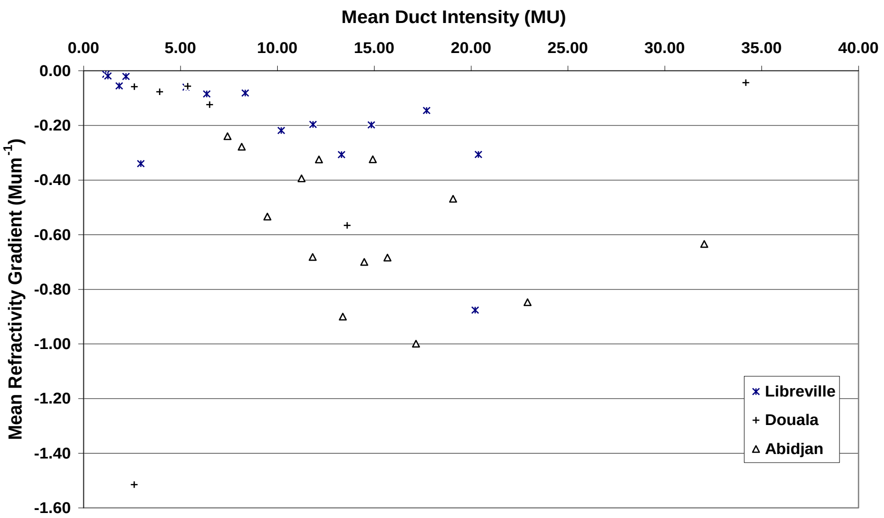

Figure 2: Mean Refractive Gradient and Mean Duct Intensity

Figure 2 captures the true situation of the region's tropospheric behaviour. *MU* is the unit of the modulus refractivity and MUm^{-1} is modulus of refractivity per metre. The cumulative probability distribution for the refractivity gradient. The mean refractive values for Abidjan are comparatively low with about -1.00 MUm^{-1} to -0.24 MUm^{-1}, a range of 0.76. Her mean duct intensity values are between 6.5 *MU* and 32.0 *MU*, a range of 25.5, these taken over a four years period. Douala on the other hand has mean refractivity gradient values of -0.06 MUm^{-1} to -1.52 MUm^{-1}, a range of 1.46. Her mean duct values are between 2.5 and 24, a range of 21.5, these taken over a two years period. While Libreville's mean refractivity gradient values are between -0.01 MUm^{-1} and -0.88 MUm^{-1}, a range of 0.87. Her mean duct intensity values are between 0.1 *MU* and 20.0 *MU*, a range of 19.9, these taken over a four years period. By these results, it is clear that Abidjan has weakest variability within the ducts with highly well-form ducting layers compared with the other two stations. Douala has strongest variability within the ducts with well-formed ducting layers. Libreville, however, is within the two boundary structure, that is slightly higher variability than Abidjan and fairly less formed ducting layers than Douala.

Looking at Table 2, Abidjan and Douala troposphere exhibit more presence of surface duct and surface-based duct. Abidjan and Douala percentage value are 85.2% and 75.4% for surface duct and 26.2%, 45.6% for surface-based duct compared to Libreville percentage values of 34.5% and 10.1% respectively. Douala troposphere has the highest order of variability, though by surface duct, Abidjan is greater but the cumulative values of surface duct and surface-based duct make Douala's troposphere variability impact greater. Libreville has the highest percentage value of 48.2% for elevated duct presence. This implies that Libreville troposphere would exhibit greater variability at the higher level of the lower troposphere.

Table 2: Percentage Occurrences of Trapping Duct Layers

Location	Surface duct %	Surface-based duct %	Elevated duct %
Abidjan	85.2	26.2	6.5
Douala	75.4	45.6	10.5
Libreville	34.5	10.1	48.2

3.2Worst-Case Scenario for the Stations Considered

Abidjan has 91.9% worst-case situation in the upper layer of the total upper layer ducting events and 88.1% worst-case in the lower troposphere of the total lower layer ducting events. Douala has 27.9% worst-case situation in the upper layer of the total upper layer ducting events and 59.3% worst-case in the lower troposphere of the total lower layer ducting events. Libreville has 84% worst-case situation in the upper layer of the total upper layer ducting events and 83.6% worst-case in the lower troposphere of the total lower layer ducting events.

Abidjan is humid throughout the year and experiences rain during the dry season as shown by her warm and dry, hot and dry, and hot and wet seasons thereby showing some remarkable ducting phenomenon. This sense of humidity makes it have the highest worst-case ducting occurrence both at the upper and lower tropospheric layers as compared with the other two stations; for the wet term of refractivity contribution in this respect is usually significant. Douala has warm and humid weather condition with relative constant temperature throughout the year. This sense of temperature makes it have high worst-case condition but less severe compared to Abidjan. Libreville on the other hand has warm climatic condition and having some worst-case situation.

This ducting that occurs in the lower troposphere significantly influences the performance of wireless communication system [19]. Without any doubt, the three stations studied have proven to show constantly changing weather pattern which heavily induce duct formation at the lower troposphere thereby contributing to the occurrence of multipath fading and signal enhancement.

3.3 Findings

This study reveals that ducting phenomenon is a continuous occurrence and governed by the meteorological patterns of the troposphere which are evident on the locations selected for this work. Meteorological data obtained at the three stations in the Gulf of Guinea over 2 and 4 years were used for the analysis. The main findings of our results are as follows:

a) Duct thickness is generally low in the 3rd quarter of the year for all the locations studied as compared with other quarterly ranges.
b) Duct presence is throughout the year and conspicuously varied which confirms [20] in each quarter.
c) The number of duct occurrences is seasonally different as stated by [18] and occurrences in the 1st and 4th Quarters accounts for more than 60% of the total representing the months of October – March (tropical dry season). This is confirmed in the work of [21] for the case of Douala specifically.
d) Duct occurrence at the upper tropospheric layer is small in number while it is more in number for the lower tropospheric layer.
e) Duct occurrence tends to be less as the tropospheric layer becomes thicker and higher.
f) Radio signals will be more and severely affected at the lower troposphere than at higher layer.
g) In terms of increasing order of variability, Douala is first, followed by Libreville and then Abidjan last.
h) In terms of increasing order of well-formed ducting layers, Abidjan is first, followed by Douala and then Libreville last.
i) In terms of increasing order of worst-case scenario, at the upper and lower layer, Abidjan is first, followed by Libreville and then Douala last.

The mean thickness of the layer over which ducting conditions occur is usually very small for near surface events and large for the upper tropospheric events.

4. Conclusion

We have explicitly looked into the meteorological condition of the troposphere of some regions of the Gulf of Guinea over which radio communication signals propagate and have been able to establish a correlation between radio duct occurrence in the tropospheric layers and refractivity gradient variation. The altitude where pronounced ducting phenomena occur majorly is within the first 300m of atmosphere above sea level for Abidjan, whereas, in Douala, it is 180m and in Libreville, it is 160m. The relatively long-term observations made during this study confirm the fact that the constantly changing weather patterns in the troposphere are directly responsible for the occurrence of radio duct and enhanced signal strength [22] at certain periods of the year. In these regions communication systems designed without accounting for the refraction effects, particularly ducting phenomenon could potentially suffer interferences. This confirms what [19] stated in their work that consideration of refractive properties of the lower troposphere is important when planning and designing terrestrial communication systems mainly because of multipath fading and interference due to trans-horizon propagation.

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