Impact of Anomalous Propagation on Communication Signals In Librivelle - Gabon Troposphere

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***Abstract*: Radio ducting is a known problem in the coastal areas of the world where it is evident that they occur frequently and their probabilities of occurrence pose enough operational effects on current radio communication signals. In this work, Advance Refractive Effects Prediction System (AREPS) is employed to characterize the tropospheric condition of Libreville troposphere. The results showed that in Libreville, the altitude where pronounced ducting phenomenon occurs majorly is within the first 160m above sea level. More so, there is an increasing order of variability and well-formed duct layers. The mean thickness of the layer over which ducting conditions occurred is usually very small for near surface events and large for the upper tropospheric events. Duct presence is throughout the year and conspicuously varied all year round.**

***Key words:* Refractivity, Ducting, Tropospheric layer, AREPS, Variability, Occurrence, Communication**

I. INTRODUCTION

Over the years, there had been tremendous growth in the demand for wireless mobile communication networks and these networks are not without its' problems and challenges. Radio waves that propagates through the atmosphere have shown to have remarkable behaviours as they encounter varying meteorological conditions proved by several research studies in tropospheric refractivity and refractivity gradient. Ducting behaviour has been attributed to the variations of the humidity, temperature and pressure that cause variations in the refractive index [26]. The resultant effect is increased fading on communication links and consequently decreased power levels at the receiver stations [22].

Libreville is the chief port and capital of Gabon. Gabon's west coast faces the South Atlantic Ocean; the weather in Libreville (0.45^0 N, 9.41^0 E, and 15 meters above sea level) is generally warm. December and January could be the warmest months, while June and July are the driest. Throughout the month of November daytime temperatures generally reach highs of around 29°C (85°F). At night the average minimum temperature drops down to around 23°C (74°F) [6].

Ducts exist whenever the vertical refractivity gradient at a given height and location is less than –157 N/km. The existence of ducts is important because they give rise to anomalous radiowave propagation, particularly on terrestrial or very low angle earth-space links. Ducts provide a mechanism for radiowave signals of sufficiently high frequencies to propagate far beyond their normal line-of-sight range, giving rise to potential interference with other services [18]. They also play an important role in the occurrence of multipath interference although they are neither necessary nor sufficient for multipath propagation to occur on any particular link [17].

For recent researches and advances in the refractivity variations of the troposphere caused by meteorological activity of the atmosphere are domicile in research archives. In other localities within the Gulf Coast of Guinea are some available researches on anomalous propagation of the troposphere have been reported in some localities in Nigeria like Akure by [2], and in Calabar by [12]. Others are Warri, Ondo, Ikeja, Ibadan, Abeokuta, Uyo, Asaba, Port Harcourt, etc by [7], [3], and [15]. Each, advanced radio refractivity variation in different way and have uniformly ascertained that irregularity of the troposphere affects radiowave propagation in Nigeria. Reference [21] focused his work on Douala troposphere and determined the AP days at the coastal site of Douala in Cameroun and observed that the surface ducts occur less frequently in the dry season over the Gulf of Guinea. Reference [19] investigated vertical gradient of refractivity of Dakar, Niamey and Douala from 2 years radiosonde data and found that most duct occurrences are in the night, morning (0000, 0600 UTC) and late afternoon (1800 UTC) respectively in the West Africa region. However, these works did not give insights to AP's impact on communication signal as well as duct thickness and its variability within its formation.

References [13], [5], [7] and [4] all used measurements campaign for their data capture and employed models such as statistical distributions of the refractivity, New Path Loss Model (NPLM), Semi- empirical model, Parabolic Equation

(PE) method and other known models. However, one unique missing link that commonly cuts across most of them is the absence of the use of daily averages for their analysis.

Most radio communication networks located in coastal areas are potentially prone to anomalous propagation [9] and the Gulf Coast of Guinea has been specifically referred to be a known problem areas of ducting [10]. The scenario in Libreville is not exceptional; therefore, many of the lower atmospheric communication systems operating in Libreville are under the influence of ducting phenomena, the need to understand its effect on communication signals is important. Meteorological statistics has shown that anomalous propagation [1] could be more frequent, their probability of occurrence is still important enough to have operational effect on current radio communication signals in this populous city of Gabon. The prospect of lost communication between two or more communicating devices with links to other dependent nodes and networks is indeed a thing of concern as radio signals very often experience outages and distortions lasting several hours and causing some grave consequences on their dependent supports.

This work is aimed at characterizing radio wave anomalous propagation conditions and their potential effects on a regional weather communication networks that is in use or to be developed and deployed in the Libreville region of Gabon.

II. MATERIALS AND METHODS

1) *Data Capture:* Radiosonde data of 64500 FOOL Libreville observation station (0.450 N, 90 E) at 12Z obtained from the University of Wyoming, College of Engineering, Department of Atmospheric Science USA was used. The 12Z was selected owing to the fact that readings from the other two time slots (i.e. 6Z, and 00Z) as well as some monthly readings were incomplete. The datasets cover the period of 2000, 2001, 2002, 2003 and 2018 respectively and the radiosonde parameters considered were the temperature, relative humidity, pressure and height. Analysed meteorological data spanned a maximum height of 1000m above the ground because radio duct that trap VHF/UHF radio signal are mainly formed in the lower troposphere [11].

2) *Method:* As anomalous propagation (AP) is due to relatively small variations of the air refractive index n, the magnitude known as refractivity *N*, defined as one millionth of *n - 1*, is commonly used in AP studies. Reference [9] had shown from the works of [8] that *N* can be written as:

$$N = (n-1) = \frac{77.6}{T}\left(p + \frac{4810e}{T}\right) \quad \text{..........(1)}$$

where *T* is the air temperature (K), *p* atmospheric pressure (hPa) and *e* is the water vapour pressure (hPa). A related magnitude is the modified refractivity *M*, which is defined as:

$$M = N + \frac{z}{10^{-6} r} \quad \text{..............................(2)}$$

where *z* is the altitude and *r* is the radius of the Earth in metres. A negative gradient of *M* is considered useful indicator as to the occurrence of ducting [14].

For tropospheric propagation, refractivity height gradient determines the path and this was obtained by differentiating equation (1) with respect to height and given as:

$$\frac{dN}{dh} = 77.6\left[\frac{1}{T}\frac{dP}{dh} - \frac{1}{T^2}\left(P + \frac{9620e}{T^3}\right)\frac{dT}{dh} + \frac{4810}{T^2}\frac{de}{dh}\right] \quad \text{....(3)}$$

Equation (4) is given by [23] as:

$$\frac{\partial N}{\partial h} = -0.0119N^2 + 6.7118N - 980.52 \quad \text{......(4)}$$

Equation (4) enables the estimation of refractivity gradient that is absolutely dependent on refractivity *N* values. This helps to capture every fluctuation in the values of temperature, pressure and humidity of the atmosphere under consideration.

The gradient of the modified refractivity gradient determines the refraction type, while tropospheric ducting phenomena occur when the following conditions is met [16]:

$$\frac{dM}{dh} < 0, \; or \; \frac{dN}{dh} < -157 \quad \text{......... (5)}$$

Advanced Refractive Effects Prediction System (AREPS) has also been employed to study the effects of radio ducting in Libreville troposphere. AREPS is a Graphics User Interface (GUI), that incorporates environmental and communications system input with the Advanced Propagation Model (APM). The output is two-dimensional views of vertical M-profiles, and propagation condition summaries based on model calculations. Meteorological data of temperature, pressure, humidity and height were entered into AREPS Environmental Creator - View Refractivity Summary platform and results obtained are succinctly presented and discussed in the next section. In this work, each year is divided along quarterly symmetry in order to aid discussion and comprehension.

For the purpose of discussion, the base of the lower troposphere (surface layer) is considered as between the station level (15m) and a vertical height of 300m. The upper troposphere is considered as between vertical height of 300m and 1000m above sea level. AREPS program computes and display a number of tactical decision aids. This decision aid is displayed as a function of height. All calculations depend on atmospheric refractivity data obtained from Department of Atmospheric Science, University of Wyoming USA [20]. Table 1 clearly specify the stations and the years considered for the study.

Table I: Libreville Station, Years and Months Considered

Douala Station	Month
Year	
2000	January to December, except April
2001	January to December
2002	January to December
2003	January to December
2018	*13th August Only

*No available data from 2004 till date. One day data of 2018 not sufficient to match available data from preceding years' analysis, due to radiosonde incompleteness for 2018

III. RESULTS AND DISCUSSION

1) Gabon Librevelle Scenario:

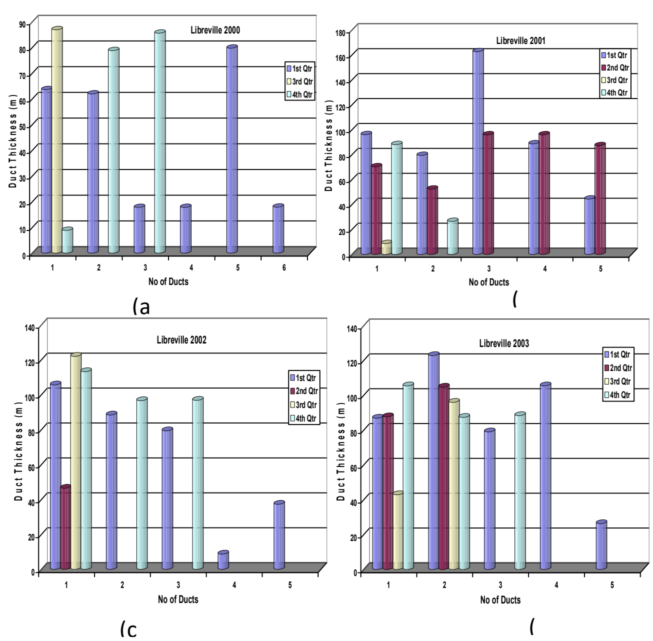


Fig. 2 Duct Thickness versus Number of Duct occurrences for Libreville in the year (a) 2000 (b) 2001 (c) 2002 and (d) 2003

Duct occurrence varies during the year as shown in the figure 1. Considering the fact that Libreville station is 15m above the sea level. The present study for Libreville comprises of 47 months with 140 days considerations of year 2000, 2001, 2002, 2003 and 2018 respectively. A total of 140 profiles were plotted out of which 38 showed ducting phenomena. This is 27.34% of the total considerations. Figure 1a and 1b are samples of profiles among several profiles obtained from the analysis.

2) Thickness of Ducting Layers for Libreville: The mean thickness over which ducting conditions occurred for the total event for Libreville is 73.09m. For near the surface events (lower troposphere), the mean thickness is 75.24m, this accounts for 91.75% of duct occurrences. This shows that duct occurrence at the surface layer is large in number, thicker and longer in layer. Events at higher altitude show a mean thickness of 55.48m and this as well accounted for 8.25% of total occurrences. This shows that duct occurrence at the upper layer is small in number and thinner in layer. Implication of these attributes is that duct occurrence for lower troposphere is more in number than that for upper layer. And the relationship between duct occurrence and height or thickness of radio duct is equally such that duct occurrence probability tends also to be less as the atmosphere becomes thicker and higher.

Looking at Table 2, it shows that the 1st quarter in the year 2000, 2001, 2002 and 2003 has the highest percentage duct thickness. The 4th quarter of year 2000, 2002 and 2003 has second highest percentile values. Duct thickness in the 3rd quarter is also generally low for all the periods considered. We could observe that duct presence is throughout the year and duct thickness is conspicuously similarly but not uniformly or equally varied in each quarter.

Table II**:** Percentage Distributions of Duct Thickness

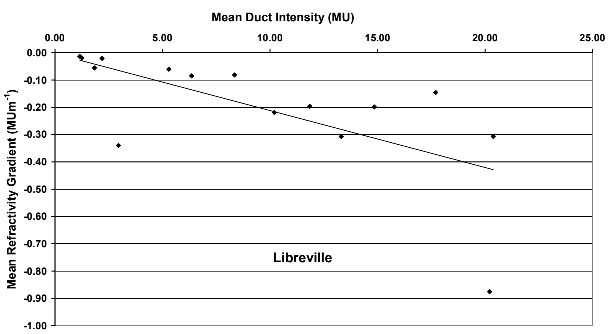
	2000	2001	2002	2003	2018
1st Qtr	7.7	14	9.5	12.5	-
2nd Qtr	-	11.9	1.4	5.7	-
3rd Qtr	2.6	0.3	4.2	4.1	
4th Qtr	5.1	3.4	9.1	8.4	-

However, the altitude where pronounced ducting phenomena occur majorly is within the first 160m of atmosphere above sea level. Further analysis shows that the majority is actually at the lower tropospheric region.

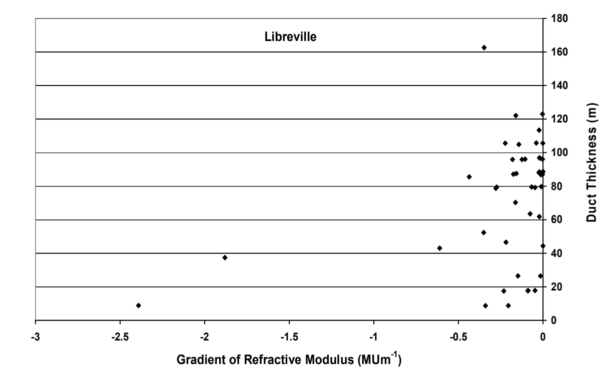
Moreover, perusing through Figure 2 (a, b, c and d), the 1st quarter has 6 duct occurrences in year 2000 and 5 in year 2001, 2002 and 2003 respectively. The 2nd quarter has no duct occurrence in 2000, 5 in 2001, 1 in year 2002 and 2 in 2003. The 3rd quarter has 1 duct occurrence in year 2000, 2001 and 2002; and 2 in 2003. The 4th quarter has 3 duct occurrences in 2000, 2 in 2001, 3 in 2002 and 2003 respectively. Libreville troposphere shows the least number of duct occurrences and invariably discourages the formation of ducting phenomena. This would then translate to the fact that radio communication signal would perform better with less frequent fading and multipath effects.

3) Variability of Ducting Levels: Variability of the ducting layer is investigated by similarly analysing the plots of Figures 3(a) and 3(b) respectively. From Figure 3(a) (i), shows the more of the mean strength (intensity) of duct variability lie above the regression line and are widespread over the entire troposphere. The distribution of duct intensity with respect to the refractivity gradient has properly show the presence of multipath propagation and radio range extensions which conspicuously prevailed in Libreville atmosphere. Figure 3(b) (ii), shows that the layer thickness is also directly proportional to the negative refractive gradient of Libreville troposphere. Meanwhile, the figure shows a sparse distribution of duct thickness (between 8 and 70m) at the base of the troposphere with higher values of refractive gradient (between – 2.5 and 0 MUm^{-1}). By this distribution, duct thicknesses at Libreville lower troposphere are highly variable. Near surface events show the lowest gradients. Thick and elongated duct layers at higher altitude of Libreville troposphere are concentrated between -0.5 and 0 MUm^{-1} indicating high variability.

Figure 3(b) (i) shows the strength of duct thickness as evidently strong within the values of 10 to 125 MU respectively. Whereas, low standard deviation (Std) values (between 0.0 and 0.18) with mean duct thickness between 45 and 100m are seen for the mean duct thicknesses as shown in Figure 3(b) (ii).

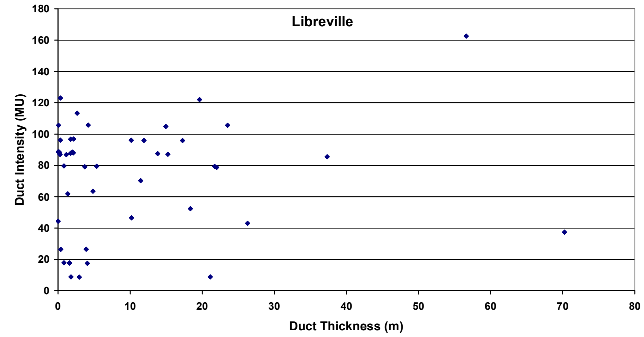


(i)

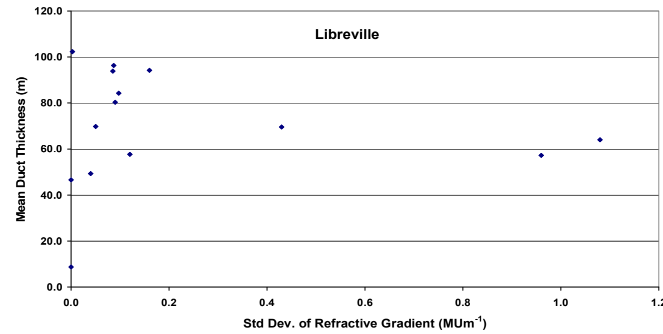


(ii)

Fig. 3(a) (i) Mean Refractivity Gradient for all Affected Events (ii) Refractivity Gradient Found for all Duct Height as Affected in Libreville Troposphere



(i)



(ii)

Fig. 3(b) (i) Relationship between Duct Layer Thickness and Duct Intensity (ii) Standard Deviation of Refractive Gradient and Mean Duct Thickness

4) Impact on Communication Signals: Our results analysed gave a vivid assessment of how a communication system would performance under the presence of anomalous propagating condition in Libreville. The performance outcome is either duct presence or duct absence in Libreville troposphere and that duct absence would mean radio communication signal range not extended beyond radius of signal coverage but propagation loss increases with range signifying that signals fade as receiver distance and height increases. This in essence confirms what [3] 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.

III. CONCLUSION

This study reveals that ducting phenomenon is a continuous occurrence and governed by the meteorological patterns of the troposphere which are evident on the Libreville troposphere. Duct occurrence varies during the year as seen in the results. Libreville has warm and humid weather condition with relative constant temperature throughout the year. Surface ducting is increasingly variable with well-formed ducting layers. 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. Duct presence is throughout the year and conspicuously varied in each quarter. The number of duct occurrences is seasonally different and occurrences in the 1st Quarters averagely accounts for 40% or more of the total which represent the months of January – March (tropical dry season).

In Libreville, the altitude where pronounced ducting phenomena occur majorly is within the first 160m of atmosphere above sea level. Radio communication signals within this height ranges would experience strong and frequent impairments. The relatively long-term observations made during this study confirm the fact that the constantly changing weather patterns in the Libreville troposphere are directly responsible for the occurrence of radio duct and radio signal enhancement at certain periods of the year. Importantly, this research outcome would assist fellow researchers to continue from where this work had stopped as updates would be highly encouraged.

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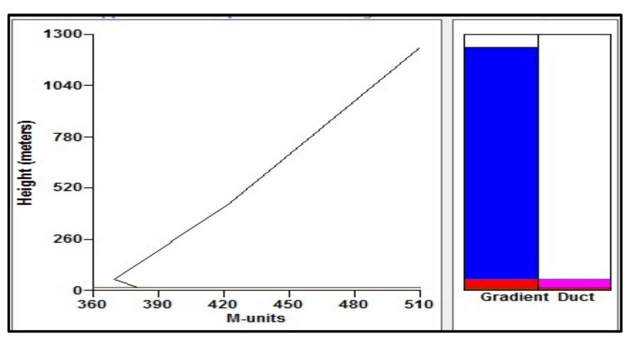
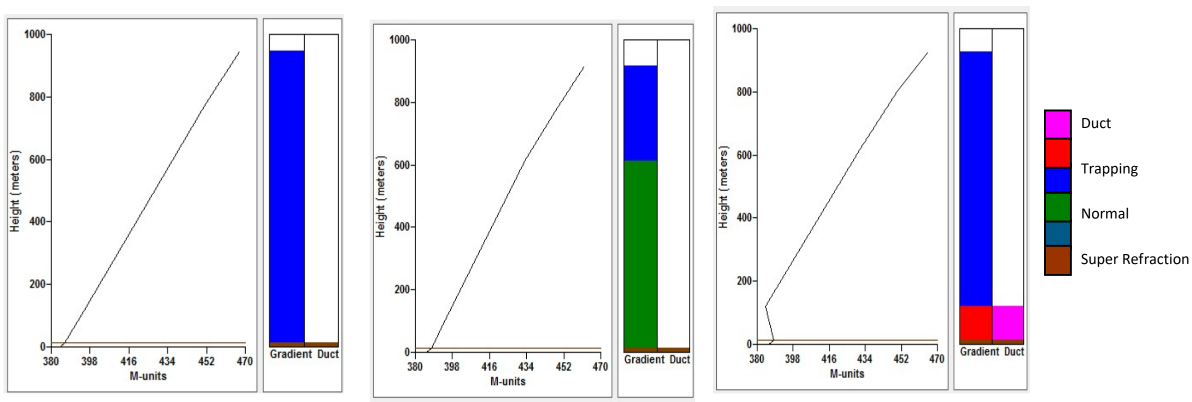
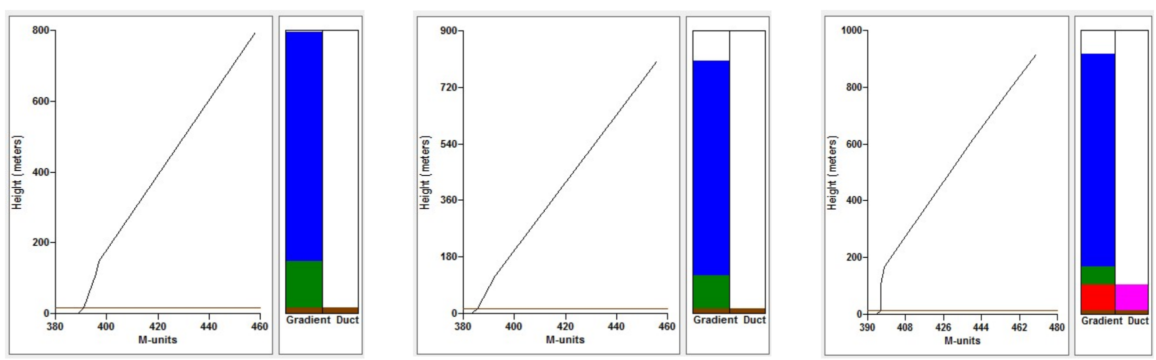


Fig. 1a Libreville Scenario for 3rd Quarter (a) January 2018



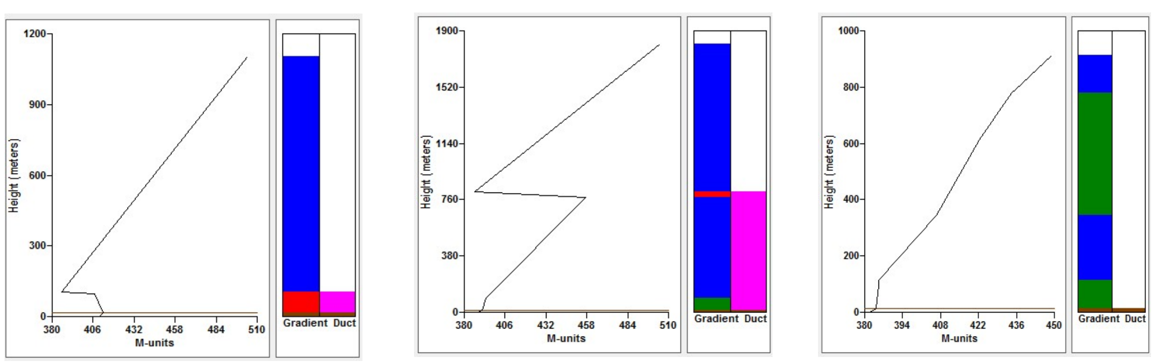
(i) 5th Jan (ii) 16th Jan (iii) 26th Jan

(a)



(i) 2nd Feb (ii) 18th Feb (iii) 27th Feb

(b)



(i) 7th Mar (ii) 22nd Mar (iii) 29th Mar

(c)

Fig. 1b Libreville Scenario for 1st Quarter (a) January 2002 (b) February 2002 (c) March 2002