NIPES

Journal of Energy Technology and Environment

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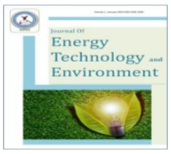

Tropospheric Duct Presence and their Effects on Communications Signals in Abidjan, Douala and Libreville

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Article information

Article History
Received 22 January 2022
Revised 8 February 2023
Accepted 25 February 2023
Available online 16 March 2023

Keywords:
Troposphere, Propagation Loss, Surface Duct, Trapping layer, Communication Signal,

https://doi.org /10.5281/zenodo.7741288

https://nipesjournals.org.ng

Abstract

Duct layers are found to be common occurrence in coastal areas of the world where their behavior is stochastic in nature and infringes on wireless radio communication. In this work, Advance Refractive Effects Prediction System (AREPS) was used to predict the presence of duct phenomena in the Abidjan, Douala and Libreville regions. AREPS was used to compute and display decision profiles with radiosonde data from Abidjan, Douala and Libreville. Results show that Abidjan's troposphere exhibited more presence of surface duct with 85.2% occurrences and Douala troposphere exhibited more presence of surface-based duct with 45.6% occurrences. Libreville with elevated duct has 48.2% occurrences. With specific focus on Abidjan, the scenario shows that the propagation loss increases with range but with steady decay throughout the range signifying that the communication signal extended beyond the target. The outcome of this study is expected to provide the regional understanding of tropospheric ducts presence and their pattern for the design and deployment of communication networks

1. Introduction

It is worth noting that studies on tropospheric ducting in many African regions are ongoing. Much ground needed to be covered as we look at the Gulf Coast of Guinea – a region of the coast of Atlantic Ocean, Western Africa. Ikharo and Amhenrior [1] had point out that the Gulf Coast of Guinea have varying degrees of comparable climatic anomalies in vertical and horizontal stratification. The performance of communication signals can be implicitly influenced by the environment in which the systems are deployed. Under certain atmospheric condition refractive effects result in ducting phenomena, skipping zones and increased shadow zones. These phenomena lead to pre-emptive benefits and drawbacks. For instance, as benefits, ducts lead to extended communication ranges thereby providing coverage to locations where unintended users are or where such signals are not needed. The drawback is that interference and skipping zones are created that generally coexist with the established duct layers and these reduce signal quality.

The bending of radio ray trajectory depends on the vertical distribution of radio refractivity in the troposphere. This distribution causes the formation of layers called duct at different locations and at different heights depending on the changing values of the tropospheric parameters. The detection of duct height is important and relevant to the understanding of the behavior of radio signals in the troposphere and its effect on wireless applications [2]. It should be noted that the duct height is a height below which an antenna must be located in order to have extended propagation. It is a value that relates to the duct's strength or its ability to trap Electromagnetic (EM) wave. A duct is a channel in which electromagnetic energy can propagate over great distances and also a channel through which wave energy leak away. To propagate energy within a duct, the angle the EM energy makes with the duct interface must be small, usually less than 1 degree [3]. Ducts not only give extended radio detection or intercept ranges for systems within the duct, it changes the normal lobe pattern caused by the interference of the direct ray and the surface-reflected ray. In situations where the meteorological conditions – temperature inversion, cause a trapping layer to occur, such that the base of the resultant duct is at the earth's surface, a surface duct is formed. There are three types of surface ducts based on the trapping layer's relationship to the earth's surface [4]. The first type is a surface duct created from a surface-based trapping layer. This duct is referred to as a surface duct. The second type of surface duct is created from an elevated trapping layer. This duct is commonly referred to as a surface-based duct. Surface-based ducts occur when the air aloft is exceptionally warm and dry compared with the air at the earth's surface. The third type of surface duct is the one created by a rapid decrease of relative humidity immediately adjacent to the air-sea interface. This duct is referred to as an evaporation duct [5].

Meteorological observations are used for real-time weather analyses, forecasts, study of climate, and for research in meteorology and climatology as well as in radio transmissions. For terrestrial line – of – sight (LOS) links and multipath links, the transmission medium is the troposphere, with varying climatic conditions that affect the propagation of radio waves. Usually, service availability of 99.99 % for the worst scenario should be the design goal for fixed links [6]. The anomalous propagation which is the outcome of the tropospheric behavior has been attributed to the variations of the pressure, humidity, temperature [7], [8]. Coastal areas of the world have large presence of super-refractive layers and the ducts that is formed affect microwave propagation [9], implying that the Gulf Coast of Guinea is no exception. Therefore, many of the lower atmospheric communication systems operating in this region are susceptible to ducting phenomena. No wonder, users in this region experiences intermittent signal failures from fractions of second to several hours at both peak and low traffic congestions.

In the work of [16], impact of anomalous propagation on communication Signals in Libreville – Gabon troposphere was investigated and established within an altitude of 160m as region of pronounced ducting occurrences for the environment. [17] similarly worked on inversion for inhomogeneous surface duct without a base layer based on ocean-scattered low-elevation Bei Dou Navigation Satellite System (BDS) signals and showed that the received power is more sensitive to the surface duct without a base layer. A real-time global tropospheric duct threat monitor was proposed to predict tropospheric delays by [18]. ERA-5 numerical weather model (NWM) data and a proposed threat monitor were deployed to analyse the ability of the monitor to predict ducting induced ranging errors at Singapore with accuracy of within ± 50 cm 95% of the time frame. [19] worked on GPS signal propagation in tropospheric ducts using parabolic equation and ray tracing methods and obtained positioning error occurrences due to the presence of ducts. Also, study on the influence of tropospheric ducts on radio propagation over sea surface was made by [20] using only parabolic wave equation and obtained elevated-surface duct appearing separately and with evaporation duct together over the sea surface. This study tends to established duct occurrence, variability, range and their effects on propagating signals in the study area troposphere using Advanced Refractive Effect Prediction System (AREPS) model.

Communication signals require seamless connectivity to be able to provide reliability network for the propagating environment, the Gulf Coast of Guinea, to allow for these effects to be taken into account and resources deployed to their best effect. In this region, communication systems designed need compensative mechanism to mitigate the refraction and ducting phenomenon. Attention is paid on the three localities of the Gulf Coast of Guinea. This region is analyzed as comprehensive representation of the Gulf Coast of Guinea.

2. Materials & Methods

2.1 Advanced Refractive Effect Prediction System (AREPS) model data sets

AREPS is used to model data from 65578 DIAP Abidjan, 64910 FKKD Douala and 64500 FOOL Libreville observation stations obtained from Department of Atmospheric Science, University of Wyoming [10]. The radiosonde parameters considered were the temperature, relative humidity, pressure and height. Data available for use were the years 2000 to 2003, 2008, 2009 and 2011. The 12Z was selected owing to readings completeness on this time slots compared to other available time slots. The vertical height of 1 km range is considered because of radio duct that trap VHF/UHF radio signal are mainly formed in the lower troposphere [11].

2.2 Derivation of Refractivity Equation for Ducting Phenomena

The refractivity of a given section of atmosphere is given by equation (1) [12]. Since the real atmosphere never remain constant at any particular time or place, a hypothetical model must be employed as an approximation to what may be expected.

$$N = 77.6\frac{P}{T} + \frac{3.73(10^5 e)}{T^2} \text{ .... (1)}$$

Table 1: Study Sites Indicating Geographical Areas

Location	Lat	Long	First Bearing	Bearing Increment	No. of Bearing
Abidjan – Ivory Coast	5° 25′ N	4° 2′ W	0	10	1
Douala – Cameroon	4° N	9.7° E	0	10	1
Libreville - Gabon	0.45^0 N	9.41^0 E	0	10	1

For tropospheric propagation, refractivity height gradient determines the path and this was obtained by differentiating equation (1) with respect to height equation (2) is obtained [16]:

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

Equation (3) is given by [13] as:

$$\frac{\partial N}{\partial h} = -0.0119N^2 + 6.7118N - 980.52 \text{ ....(3)}$$

Equation (3) 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.

2.3 Ducted Ray Paths Close to the Earth's Surface

For layer of atmosphere above the earth's surface with thickness *H* where the vertical gradient of refractivity (*dN/dh*) is less than -157N/km, and above which there is an atmosphere of very great depth, where *dN/dh* is assumed to have a value close to the normal say -40N/km. According to [15],

$$N_o + \left(\frac{dN}{dh}\right)_1 y + \frac{y}{a} - \frac{\varphi^2}{2} = N_o + \left(\frac{dN}{dh}\right)_1 y_o + \frac{y_o}{a} - \frac{\varphi_o^{\,2}}{2} \quad \ldots\ldots..(4)$$

3.0 Results and Discussions

Looking at Table 2, Abidjan and Douala troposphere exhibit more presence of surface duct and surface-based duct with percentage values of 85.2%, 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

3.1 AREPS Displays for Abidjan, Douala and Gabon

A typical AREPS project platform has five different segments consisting of decision aid, system specification, environment specification, graphic display and project geographic area for customization. Communications transceiver of Frequencies 30MHz and above (with interest in 1.8 GHz and 1.9 GHz band) is deployed. Transceiver height of 45 m and environmental model of Abidjan, Douala and Libreville costal sites were used. Other selections are made in line with obtainable parameters used for the radiosonde data and predicted data for the selected sites. It should be noted that daily averages of temperatures, pressures and relative humidity of the coastal regions were used.

Table 3 shows a typical computation obtained from AREPS. It consists of Marsden squares; each square is divided in 10 degrees Marsden squares. Douala-Cameroun is contained in Marsden 036. For each Marsden square the average ducting behaviour is provided for each month of the year. The vertical refractivity profile for the location is shown in Figure 1.

Table 3: Typical Douala-Station in AREPS Marsden Square 036

Height	M	N	Layer
10	382	382	Normal
15	382.46	381.68	Trapping
140	368.46	348.05	Normal
1140	463.46	286.05	

3.2 *Propagation predictions*

The refractivity profiles are that of Abidjan, Douala and Libreville as depicted in Figures 1 to 3. Figure 1 shows the height versus M-units profile indicating duct presence at the base of the profile (below 300m height).

Figure 2(i) is grey while Figure 2(ii) is coloured, both diagrams are the same but shown differently to illustrate the formation of anomalous propagation layers. This is the same setting for Figures 3, 4 and 5. However, Figure 2(ii) shows two duct formations, elevated and surface-based ducts. The transmitter placed on top level of the lower duct produce the formation of an elevated duct and radio signals are seen to be trapped by the duct. The duct acting as a pipe leaks away signal power and prevent these signals from reaching the target. Here, it is seen that signals originating inside the duct are those that are trapped. This implies that these rays are launched above the top of the duct and are at a critical angle below the duct horizontal boundary. At this angle, the ray can be trapped by a very small, hence unstable, trapping layer at the top of the duct. Any other ray entering from the outside will only have its course altered by the duct. Rays launched from inside the duct may or may not be trapped, again depending on their elevation angle [14]. A ray with a steep elevation angle will not be bent sufficiently to be trapped before it escapes the duct.

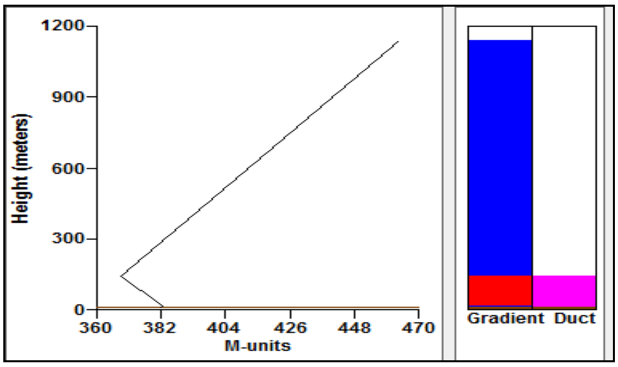
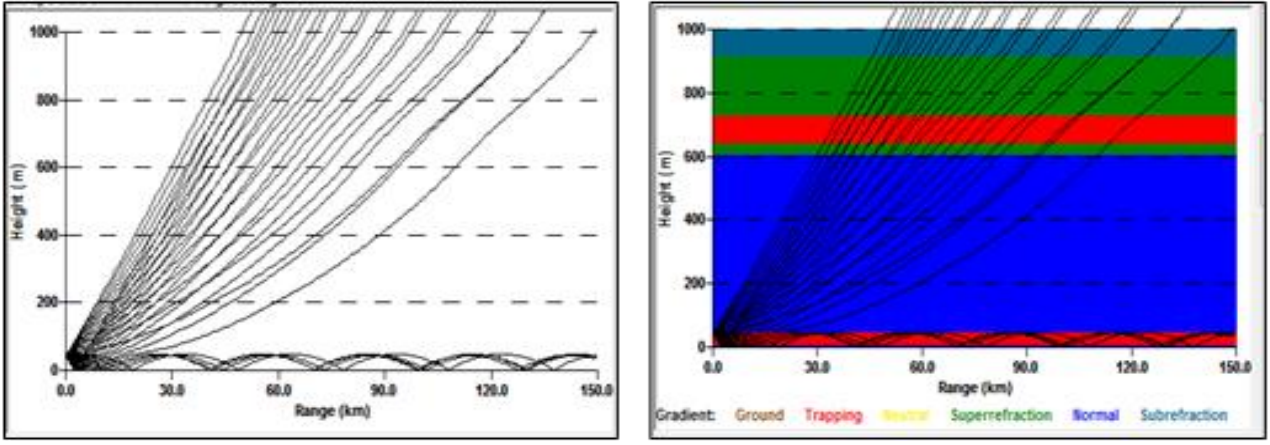


Figure 1: M-unit Profile for Douala-Cameroun Created using AREPS Database Environmental Creator



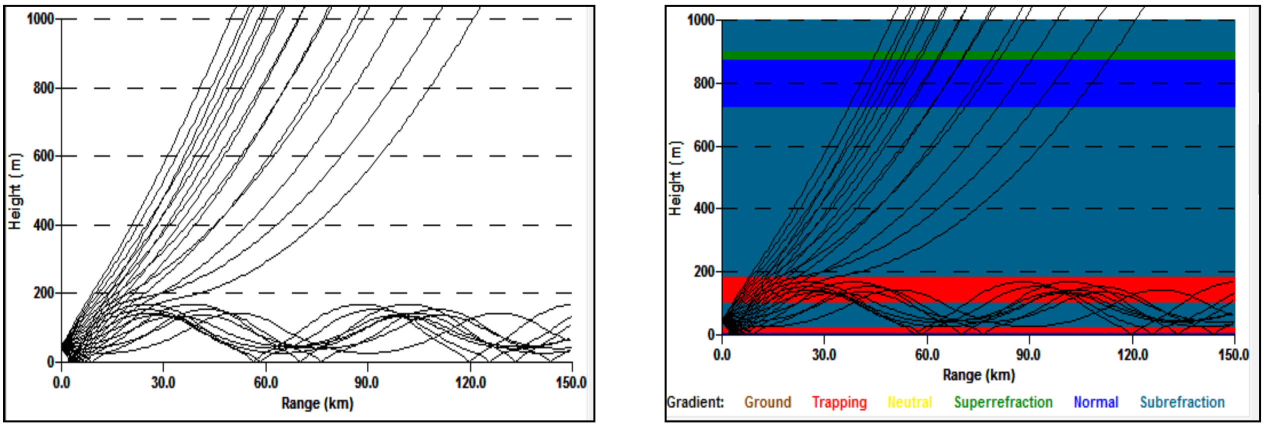
(i) (ii)

Figure 2: Abidjan Scenario February, 2000 Sampled Data

Figure 3 shows the transmitter placed between two ducting layers. The profile indicates a surface-based duct and an elevated duct with some radio signals twinning within and between the two duct layers. This in itself helps the extension of the radio range. The ducts acting as a pipe concentrate signal power within this boundary and guide the reception of strong signals to reach the target.

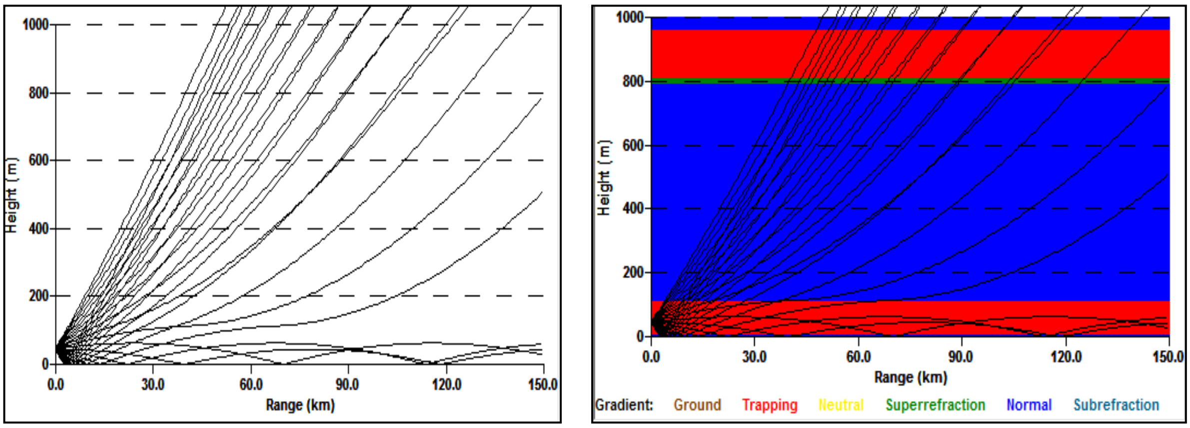
Figure 4 shows the transmitter placed between two ducting layers in similar way with Figure 2 for Abidjan scenario, except that these two duct layers are wider apart for Douala Environment. The profile indicated a surface duct and an elevated duct with very few radios signals twinning between the two layers. Majority of the radio rays are directed upward. There is the extension of radio range with less concentration of signal power within duct guided to reach the target receiver.

Figure 5 shows the transmitter placed below the two elevated ducting layers. These two duct layers are wider apart. The profile indicates an elevated duct with majority of the radio signals twinning between the lower duct layer and the surface. The lower duct layer is serving as the reflector at the upper side of the trapped signals. Few radio rays are directed upward. There is the extension of radio range with less concentration of signal power within duct and guided to reach the target receiver.



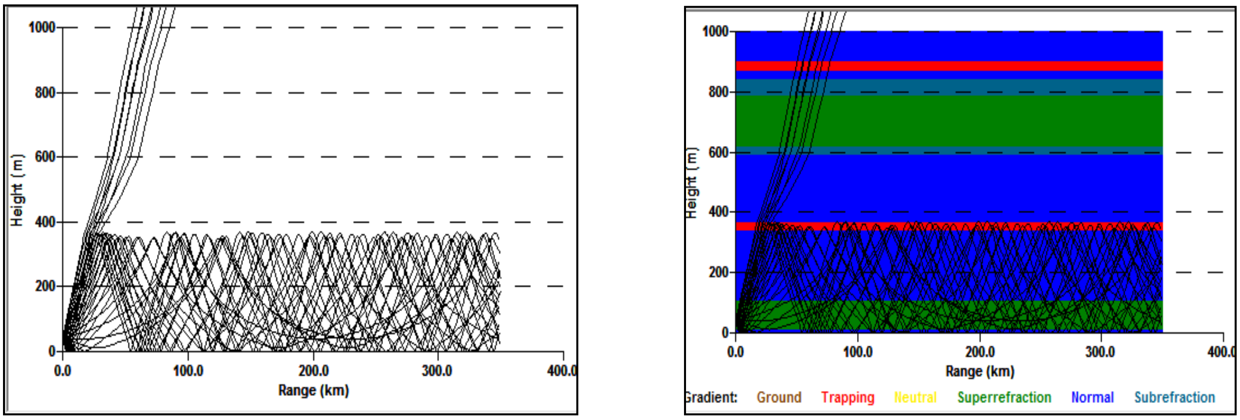
(i) (ii)

Figure 3: Abidjan Scenario December, 2000 Sampled Data



(i) (ii)

Figure 4: Douala Scenario for October, 2009 Sampled Data

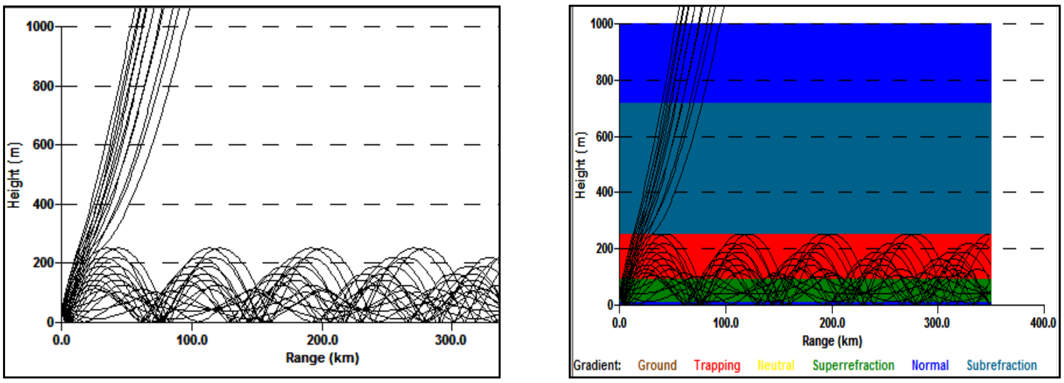


(i) (ii)

Figure 5: Douala Scenario for October, 2011 Sampled Data

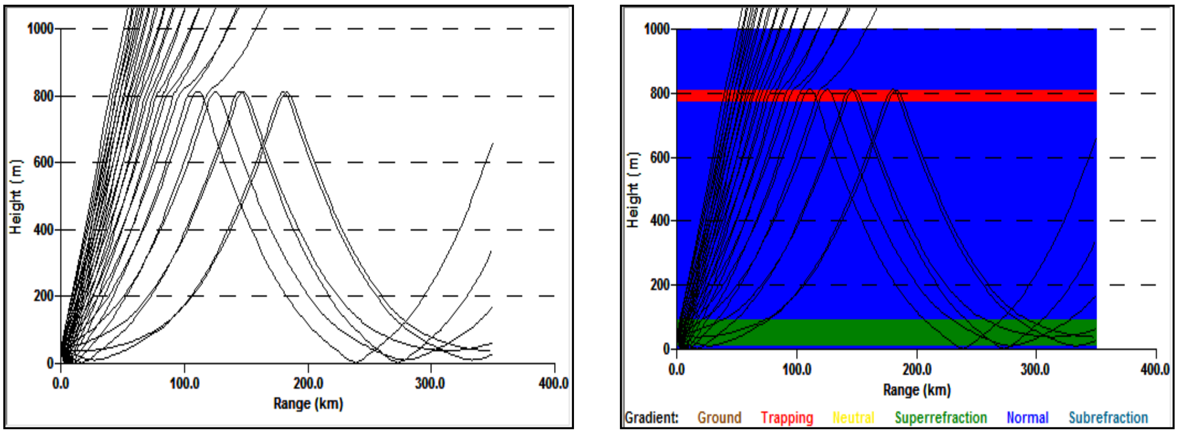
These profiles show the varying degrees of refraction with ray tracing display of ray paths along its trajectory within various tropospheric conditions in Abidjan atmosphere. Figure below shows a loss diagram for a typical coverage area using a UHF communication transceiver over a land path in the presence of surface-based duct.

Figure 6(a) shows the transmitter placed below the duct layer for Libreville environment. An elevated duct is formed and the radio signal is seen to be trapped by the duct. The duct acting as a pipe leaks away signal power and prevents these signals from reaching the target. At this angle, most of the rays are seen bent by upper level of the duct and the surface of the ground. It must be recalled that a horizontal ray path is caused by a vanishing *M*-gradient. If the *M*-gradient goes negative, the ray will be bent down towards the earth. When the initial slope (i.e., near the surface) of the *M*-profile is negative, the result is a surface duct. If the initial elevation angle of a particular ray launched from ground level is low enough, the beam will be bent back to the earth. Depending on the electromagnetic characteristics of the ground, the beam may be reflected only to be bent back and reflected again. In this way, the energy can be channelled along the surface for great distances. Figure 6(b) shows the transmitter placed below the duct layer. An elevated duct is formed and the radio signal is seen to be trapped by the duct. The duct acting as a reflector successfully turned the direction of the signal power back to the earth. At the same time refracted other ray paths and prevented these signals from reaching the target. Most of the rays are seen bent by upper level of the duct and the surface of the ground.



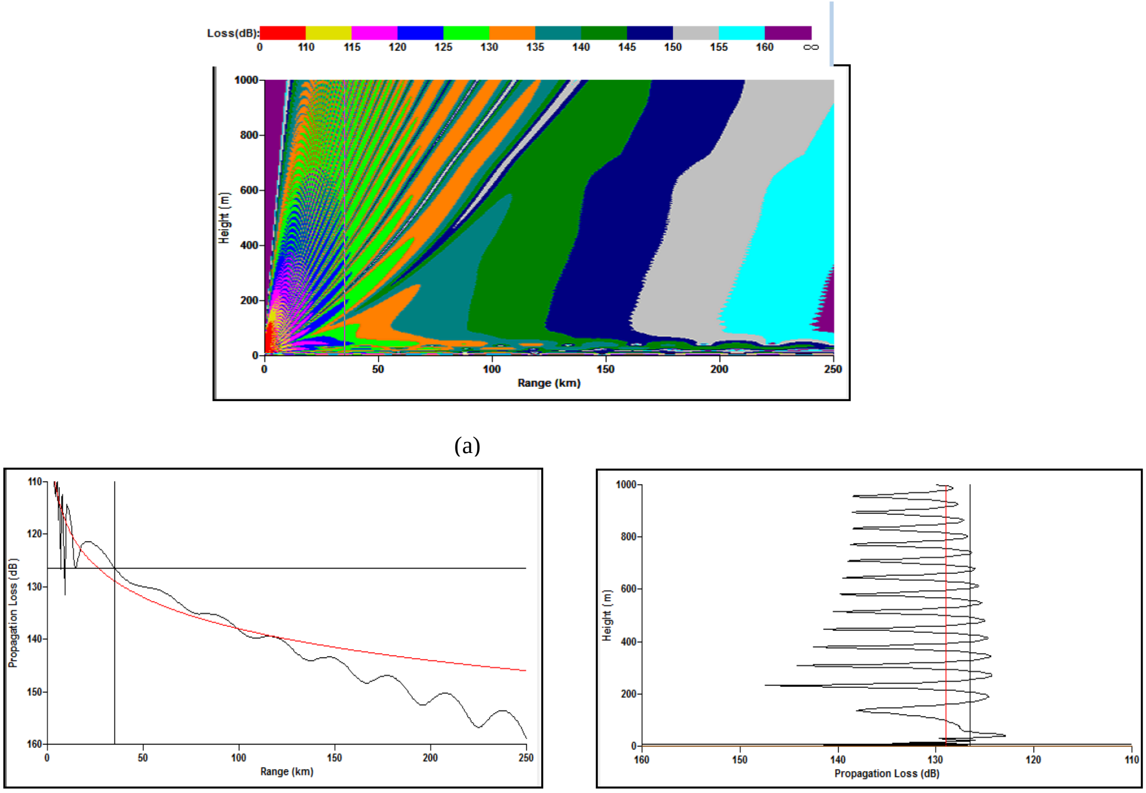
(a) (b)

Figure 6(a): Libreville Scenario for February, 2001 Sampled Data



(a) (b)

Figure 6(b): Libreville Scenario for March, 2002 Sampled Data



(a)

(b)

(c)

Figure 7:(a) Coverage Diagram of the Propagation Loss for Refractivity for 12th February 2000, Abidjan, (b) and (c) Propagation Loss profile for Abidjan for the Refractivity profiles for 12th February 2000

3.3 Propagation Loss Effects

Abidjan anomalous propagating environments is studied to further illustrate the performance of radio signals in ducting and non-ducting environments. Figure 7 illustrate the typical scenarios.

Figure 7 shows (a) height – range relation (b) propagation loss - range relation and (c) height - propagation loss relation. It shows the profile for Abidjan, February 2000. In (a) the existence of spatial regions with negative modified refractivity gradient clearly indicates the presence of ducting for Abidjan on the 7th February 2000 showing signal enhancement. In (b), propagation loss increases with range but with steady decay throughout the range signifying that the signal extended beyond the target. Though, it faded as the receiver distance increases. The signal strength is high at the radius of coverage of 20km, after this range the signal strength fades gradually. Because of the presence of duct, the signal path was extended hence receiver placed beyond 250km would receive radio signal. In (c), the signal strength is strong at the transmitter height (surface level) but as the height increases the quantum of loss increases. More so, the profile experience steady flow in the strength direction.

4.0 Conclusion

The formation of ducting phenomenon for different meteorological conditions has been investigated in Abidjan, Douala and Libreville coastal regions of the Gulf of Guinea using AREPS. The study was able to establish ducting phenomenon for different meteorological conditions existing in the three locations of the Gulf of Guinea coastal region with justifying effects on wireless communication signals operating in this region. In so doing, it has afforded us to gain insights into the extents of the processes controlling the present tropospheric propagation in these locations.

Acknowledgment

The radiosondes data used to estimate the tropospheric layers are provided by Department of Atmospheric Science, University of Wyoming and available at [10]. We do thank and appreciate their continual deployment of the radio balloon over these sites and over periods of time.

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