Climatology of radar anomalous propagation over West Africa

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Abstract

A comprehensive examination of 5 years of European Centre for Medium-Range Weather Forecasts (ECMWF) data to determine ducting conditions over West Africa and the computation of statistical distributions of the vertical gradient of refractivity determined from 2 years of radiosonde data over Dakar (14.41°N, 17.26°W), Douala (4.00°N, 9.70°E) and Niamey (13.35°N, 2.03°E) were carried out. It is found that diurnal and seasonal variations of the refractivity of the atmosphere are influenced by air temperature and water vapor pressure fluctuation. Refractivity gradients lower than - 0.157 m^{-1} often result in spurious returned echoes and misinterpretation of radar images such as erroneous precipitation detection. The results obtained show that the local climate has an appreciable influence on the vertical profile of refractivity, especially the seasonal north-south movement of the Inter Tropical Discontinuity which is associated with the alternance of wet and dry seasons over the region. It is found that most of ducts occur in the night, morning (0000, 0600 UTC) and late afternoon (1800 UTC). The occurrence probability of abnormal propagation events, such as ducts, can provide some valuable information about the propagation of electromagnetic waves over West Africa.

1- Introduction

One of the main usages of weather radars is to remotely detect precipitation position and intensity with applications such as the issue of flood warning. Weather users often need to know the amount of rainfall over large areas. Radar networks nicely complements rain gauge networks because they offer a much better spatial coverage and hence better representativity. Rain gauges can be used to calibrate radars. It is essential to know the atmospheric refractive index for applications of radars in meteorology as well as for telecommunications (Lenouo, 2012). In certain meteorological conditions, low-tilt beams emitted from ground-based radar can become trapped and can even be deflected toward the surface, leading to spurious backscattered signals and hence potentially erroneous interpretation (e.g., false precipitation echo). This phenomenon is referred to as anomalous propagation (AP), and the layer within which the beam bends downward is called the duct.

Ducting conditions have been widely investigated in various regions of the world using upper-air measurements. These studies have documented its variation with temperature at Goztepe (Dalmaz, 1977), its spatial and seasonal variability in Turkey (Barla, 1986), the conditions of radio wave propagation in Istanbul, Turkey (Mentes and Kaymaz, 2007) or the temporal variability of the refractive index at 100 m from the ground, measured at Akure, Nigeria (Falodun and Ajewole, 2006). For the latter case, the authors showed that seasonal variations of the vertical gradient of the index have extremes which correspond to the dry season and rainy season in this city. The statistical study of ducting conditions was also proposed for the Wallops Island, Virginia, using radiosonde observations at high resolution, measured from a helicopter (Babin, 1996) and in Barcelona, Spain (Bech et al. 2002). Climatological maps of the occurrence of superrefracting and ducting layers, and maps of refractivity gradient were constructed by Lopez (2009). A more recent study on refractive conditions in Bordeaux-Merignac, France, was conducted by Mesnard and Sauvageot (2010) to determine the anomalous propagations at their radar site. The propagation of electromagnetic waves emitted from ground-based meteorological radar was determined using high-resolution radiosonde data by Lenouo (2012). In his work, a detailed analysis of surface ducts has been undertaken to determine the anomalous propagation days on the coastal site of Douala (4°N, 9.7°E) in Cameroon over the Gulf of Guinea. The author found that the duct strength seasonal variability have a value over Douala of about − 7.2 M-units for 1200 UTC and − 4.5 M-units for 0000 UTC in January, whereas in July the ducts are stronger during the day (−12.8 M-units at 1200 UTC) than at night (− 9.8 M-units at 0000 UTC).

From a climatological standpoint, it is important to assess how often a given region of West Africa is likely to experience conditions favorable to AP. Despite the limitations associated with the use of model analyses with relatively limited vertical and horizontal resolutions, such knowledge might be used for guidance by radar network developers for the siting of new instruments (Lopez, 2009). As noted by Lopez (2009), it could also help to identify regions in which model verification, precipitation analysis, and data assimilation based on radar data are likely to be affected by frequent AP situations. In the literature, global maps of vertical refractivity gradients for 100 and 1000 m above ground level (AGL) were created by Bean and Dutton (1968) for guidance of communication systems design. Radiosonde data were used to produce the Historical Electromagnetic Propagation Condition Database by Patterson (1987), which was later included in the Advance Refractive Engineering Prediction System (AREPS) of the U.S. Naval Laboratory (Patterson 1998). In a similar way, the International Telecommunication Union (ITU) periodically publishes global maps of propagation conditions, some of which were based on European Centre for Medium Range Weather Forecasts (ECMWF) analyses (e.g., ITU 2003). In a more recent paper, Lopez (2009) proposed a 5-yr global climatology of AP events from the viewpoint of ground-based radars and derived from ECMWF operational analyses at roughly 40-km horizontal resolution, which should provide information on a much finer scale over individual regions. Ground-based radar observations at three distinct geographical locations in West Africa along a common latitudinal band (Niamey (13.49°N, 2.17°E), Niger (continental), Kawsara (14.66°N, 17.10°W), Senegal (coastal), and Praia (14.92°N, 23.48°W), Republic of Cape Verde (maritime)) were analyzed to determine convective system characteristics in each domain during a 29 - day period in 2006 by Guy et al. (2011). They found that ancillary datasets provided by the African Monsoon Multidisciplinary Analyses (AMMA) and NASA-AMMA (NAMMA) field campaigns and used to describe the meteorological context of radar observations show that total precipitation is dominated by propagating mesoscale convective systems.

Hence, numerous studies have investigated and discussed various aspects of the physics of the AP phenomenon, such as ducting conditions and duct distributions (depth, height, intensity). However, the duct climatology at a single point does not account for the spatial variability and occurrence of AP echoes (Mesnard and Sauvageot, 2010). Neither the horizontal extent nor the duration of ducts over West Africa have ever been clearly documented and discussed. Therefore, the purpose of our study is twofold. The first is to derive statistics of the surface ducts over West Africa using a 5-yr global climatology of AP events from the viewpoint of ground-based radars and derived from ECMWF operational analyses at roughly 40-km horizontal resolution. The second purpose is to determine the characteristics of the surface ducts and refractivity profiles that result from AP events during the years 2006 and 2007 in three towns over West Africa (Dakar, Douala and Niamey). Hence, we analyze the seasonal surface ducts frequency; an attempt to identify the meteorological differences between then is made using associated weather maps. The results of this study could be of great interest to both the civilian and military West African community as noted by Mentes and Kaymaz (2007).

The data used in this study, derived from regular radiosoundings carried out by the technical division of ASECNA (Agency for the Safety of Air Navigation in Africa and Madagascar), as well as from ECMWF analyses are briefly described in section 2. The seasonal climatology of ducting over West Africa is presented in section 3. The statistical analysis of refraction from 2006 to 2007 radiosonde data (during AMMA SOP3) are presented in section 4, which also includes a more detailed analysis of ducting occurrences over West Africa. Then, the sensitivity of the climatological statistics to radar in Niamey is discussed in section 5. Section 6 provides summary and concluding remarks.

2 Methodology and data

2.1 Methodology

The refractive index of air is close to 1 and therefore, in meteorology, the co-index N is defined as (e.g. Bean and Dutton, 1968):

$$N=(n-1)\times10^{6}=\frac{77.6}{T}\left(P+\frac{4810\ e}{T}\right) \qquad (1)$$

where *e* is water vapor pressure (hPa), T the absolute temperature (K) and P the pressure (hPa). The effect of the earth's curvature (radius R) at an altitude z can be accounted for by considering a modified refractivity M (e.g., Lopez, 2009), defined as

$$M = N + \frac{Z\times10^{6}}{R} \qquad (2)$$

The vertical gradient of the field of air refractivity in the lower atmospheric layers (below 200 m above ground) is an important parameter that influences the propagation of the radar signal (Pratte et al., 1995; Craig and Hayton,1995; Steiner and Smith, 2002). The decrease of atmospheric refractivity with height, dN/dz, directly influences the propagation of radio waves of radar. When the atmospheric refractive index decreases with height inside a temperature inversion layer or in the presence of a strong negative vertical gradient of water vapor pressure, the radar beam can be reflected towards the ground. The reflected beam upon hitting the ground is then partially backscattered towards the radar, leading to the potential misinterpretation of the signal as spurious precipitation. Four refractive regimes (associated to refractivity gradients) can be defined, whose electromagnetic signal characteristics:

$\partial N/\partial z > 0$	Subrefraction
$0 \geq \partial N/\partial z > -0.0787\ m^{-1}$	Normal refraction
$-0.0787\ m^{-1} \geq \partial N/\partial z > -0.157\ m^{-1}$	Superrefraction
$-0.157\ m^{-1} \geq \partial N/\partial z$	Ducting

Following the definition of Turton et al. (1988), a duct is a layer in which dM/dz = 0 which is equivalent to $\partial N/\partial z = -10^6/R = -0.157\ m^{-1}$. A trapping layer is located inside and at the top of a duct. There exist three main types of ducts: surface duct, S-shaped surface duct and elevated surface duct. In this work, we are focusing on surface ducts which usually correspond to evaporative surface ducts. Such atmospheric phenomena that are due to strong diurnal effects are frequent over West Africa (Derbetini et al, 2010). Varying refractivity conditions can have very important consequences on radar systems, military services, navigation systems, communication systems, microwave operations, and many other technological systems that operate on the basis of electromagnetic wave propagation in the atmosphere. Potential effects include loss of propagation, transmission fading, altitude errors for height-finding radars, decreased/increased detection ranges and shortened/extended radio horizons (Mentes and Kaymay, 2007).

2.2 Data

The climatological statistics were computed from European Centre for Medium-Range Weather Forecasts (ECMWF) operational analyses for the period between 1 December 2000 and 30 November 2005. ECMWF operational analyses are produced using a 4DVAR data assimilation system, as described in Lopez (2009). On the other hand, the radiosonde data were downloaded from the AMMA database website. The data consist of a series of two soundings per day at 1200 UTC and 0000 UTC for the period from January 2006 to December 2006. This is in accordance with the guidelines of the World Meteorological Organization (WMO). To investigate surface duct conditions over Istanbul, Turkey, Mentes and Kaymaz (2007) used radiosonde measurements recorded automatically at the Göztepe Meteorological Station on the Asian side of Istanbul near the Bosporus coast. Unfortunately, as noted by Steiner and Smith (2002) or Menard and Sauvageot (2010), traditional radiosonde data cannot be usefully related to observed anomalous propagation (AP) distribution because of the lack of vertical resolution (approximately 100 m). However, during the 2006 AMMA field experiment, West Africa towns (incl. Douala, Dakar and Niamey) benefited from recent equipment that allows observations to be made with high vertical resolution which is generally less than 10 m (Agusti et al. 2010). A comparison between surface duct occurrences obtained by using low- and high-resolution radiosonde data was made by Bech et al. (1998) for Barcelona. Their results showed that the surface duct occurrences using low-resolution radiosonde data match 83% of those determined by using the high-resolution radiosonde data. Hence, here we use high-resolution radiosonde data to study surface ducts and the local meteorological conditions determined by the relative duct occurrences and radar data to examine cloud and precipitation at Niamey. Refractivity is computed from Eq. (1), and the minimum vertical gradient is estimated over all model layers starting from the lowest model level up to a height of 2000 m. Lopez (2009) used a model level up to a height of 3000 m.

3 Seasonal climatology of ducting over West Africa

Figures 2–5 display the diurnal cycle of ducting occurrence over West Africa for winter, spring, summer, and autumn, respectively. These figures present the diurnal cycle of ducting occurrence over West Africa at 0000, 0600, 1200, and 1800 UTC, respectively. In this study, statistics are calculated for ducting situations. Super-refraction (ducting) is assumed to occur whenever the minimum value of $\partial N/\partial z$ is lower than $-0.0787\ m^{-1}$ ($-0.157\ m^{-1}$). Note that in the following, all occurrences of ducting events are also counted as super-refractive cases.

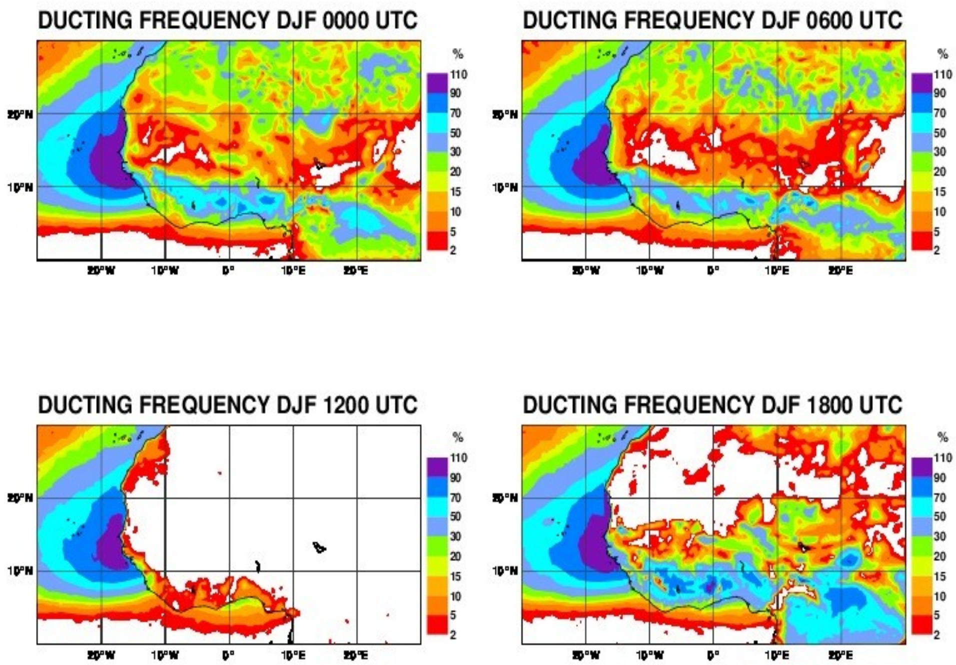

Fig.1. Mean frequency (%) of ducting conditions over west Africa for DJF at 0000, 0600, 1200, 1800 UTC. White shading corresponds to duct frenquency below 2%.

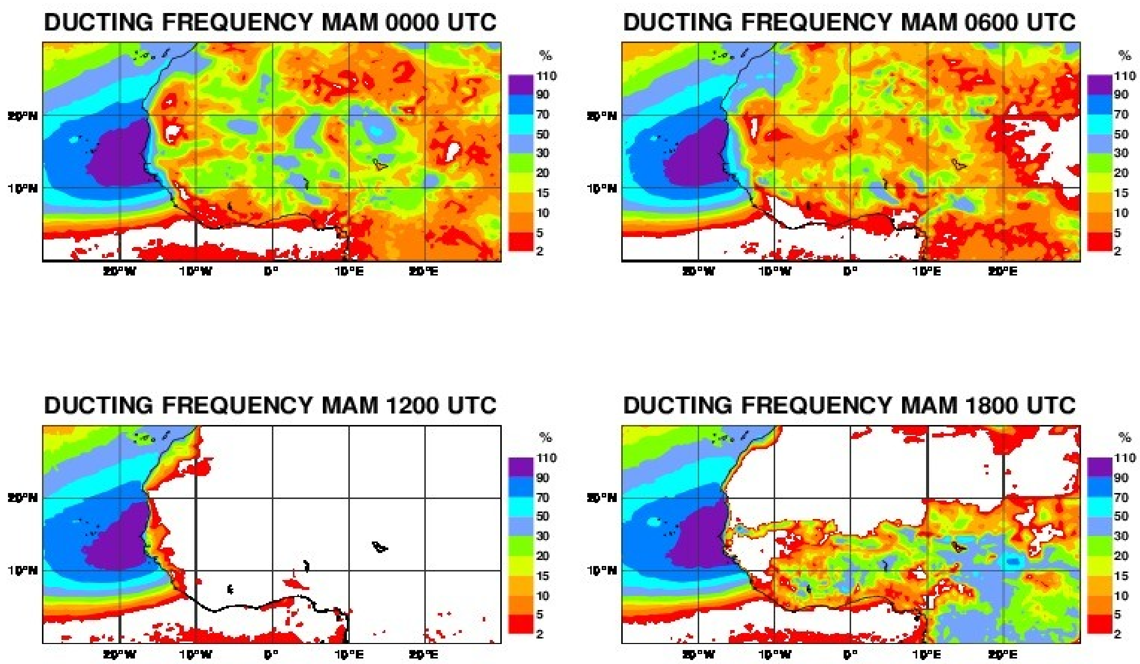

Fig. 2. As in Fig.1, but for MAM.

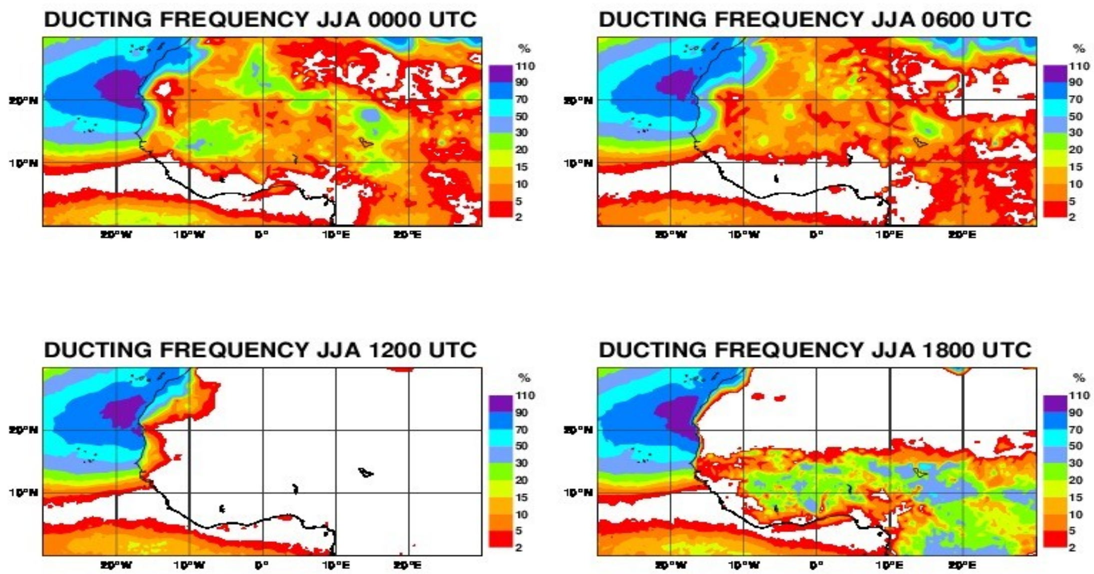

Fig. 3. As in Fig. 1, for JJA.

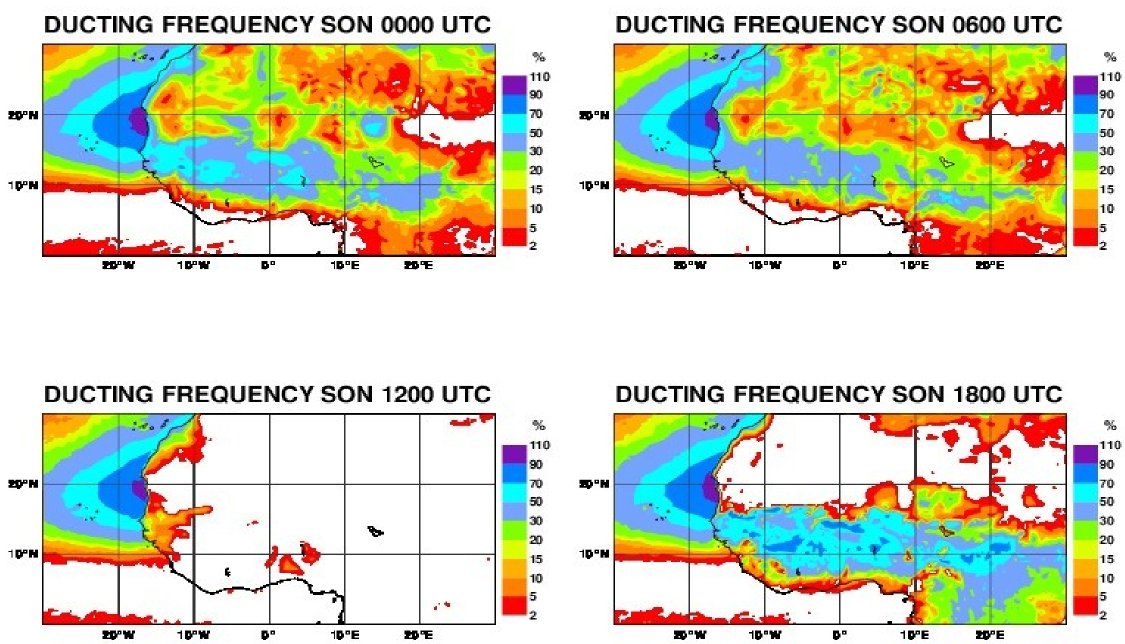

Fig. 4. As in Fig. 1, but for SON.

Over the entire West Africa, ducting frequencies are generally lower in the dry season (DJF and MAM which correspond to winter and spring respectively) and maximum in the wet season (JJA and SON which correspond to summer and autumn respectively). In all seasons, over land, ducts are almost completely absent at 1200 UTC, as seen in Figs. 1–4. Note that white shading indicates areas where ducting frequency is below 2%. The higher values obtained during the morning and night hours can be attributed to the high values of the relative humidity recorded for these hours of the day, while the lower refractivity values in the midday can be attributed to the low relative humidity which resulted from the high temperature associated with the afternoon hours. Indeed, the development of sharp low-level refractivity gradients in daytime is hindered by the intense tropospheric mixing associated with the strong solar heating and convective activity and by the relative weakness of water vapor partial pressure. From early night to early morning (Figs. 1–4, 0000, and 0600 UTC), ducts are more likely to appear as a result of the nocturnal surface cooling and increased stability that favor the buildup of low-level temperature inversion and sharper negative vertical gradients of moisture. In general, over West Africa, occurrences of ducts are more frequent at 0000, 0600 and 1800 UTC than at 1200 UTC. Throughout the year, the coastal area turns out to be the West African region with the strongest probability of ducting events, in agreement with the local climatological study of anomalous propagation events proposed by Fornasiero et al. (2006). In both dry and wet seasons, the central and the north part of the region remains virtually duct free all day long as a result of the low moisture content in the prevailing cold air masses. In general, ducting frequencies remain below 30%, except over western coastal areas at night (up to 35% locally in Figs. 1-4) and over Senegal, Guinea, Sierra Leone and Cape-Verde in late afternoon. The formation of nighttime ducts over the coastal area can be explained by the combination of prevailing stable conditions and low-level moisture advection from the nearby ocean. Figures 1-4 show that ducts disappear almost completely in daytime as a result of increased turbulence in the planetary boundary layer (PBL) throughout the region, except over the west coast. All of these results are consistent with the ducting statistics previously obtained from radiosoundings over some cities of West Africa (Falodun and Ajewole, 2006; Lenouo, 2012).

4 Statistical analysis of refraction from 2006 to 2007 from radiosonde data

The seasonal pattern of radio refractive index structure and its related parameters may be associated with the migration of the Inter Tropical Discontinuity (ITD), the fluctuations of which dictate and control the rainfall and water vapor profiles characteristic of the region. The ITD is the discontinuity lying between the moist, southwesterly, tropical maritime monsoon air mass emanating from the Gulf of Guinea, and the cool, dry, northeasterly tropical continental flow from the Sahara Desert. The ITD reaches its maximum northward position in July or August and its maximum southward extent in January (Ojo, 1977). In January, its position is approximately 6°N and all regions north of it will be under the influence of the tropical continental, resulting in dry season conditions in West Africa (Willoughby, 2002). The inland station of Niamey falls under the tropical continental influence during this period. Conditions are such that the water vapor pressures are lower, both at the surface and at 3 km level, the fractional reduction at the surface being more pronounced. These are responsible for lower values of dN/dz.

Table 1: Monthly distribution of refraction in Dakar; the refractive conditions and their number of occurrence at 0000 UTC and 1200 UTC are presented. The different propagation regimes are: sub-refraction (SUB), normal refraction (NORM), super-refraction (SUPR) and ducting (DUCT).

	SUB	NORM	SUPR	DUCT
Months	(0000/1200 UTC)	(0000/1200 UTC)	(0000/1200 UTC)	(0000/1200 UTC)
Jan	37/89	8596/8845	35/38	1/1
Feb	28/50	6826/7157	78/58	0/1
Mar	33/110	7678/8588	204/112	4/2
Apr	44/116	6316/6082	116/54	0/0
May	58/168	8606/8722	121/40	1/0
Jun	51/72	7809/6425	37/15	0/0
Jul	38/74	6951/7334	6/11	0/0
Aug	32/51	6681/6422	3/7	2/0
Sep	19/54	4724/5977	10/1	0/0
Oct	15/43	3973/4951	6/5	0/0
Nov	17/51	4716/5227	6/9	1/0
Dec	17/29	4502/4610	23/14	0/1
Mean	**29.58/76.08**	**6448.16/6695**	**53.75/30.33**	**0.74/0.41**

Table 2: The same as table 1 in Niamey

	SUB	NORM	SUPR	DUCT
Months	(0000/1200 UTC)	(0000/1200 UTC)	(0000/1200 UTC)	(0000/1200 UTC)
Jan	7/11	2161/1675	11/0	0/0
Feb	29/49	9288/6499	52/1	0/0
Mar	19/64	8574/7309	45/3	6/0

Apr	31/63	6783/6185	22/0	0/0
May	37/85	7452/6478	9/1	0/1
Jun	35/70	6731/6919	1/1	0/0
Jul	39/70	7348/6683	3/7	0/0
Aug	32/58	6530/7129	2/3	0/0
Sep	29/58	6235/6382	2/13	0/0
Oct	24/63	6342/6219	12/5	1/1
Nov	28/99	6773/6499	100/3	4/1
Dec	30/88	6463/6986	85/2	0/0
Mean	**28.33/64.83**	**6723.33/6246.91**	**28.66/03.25**	**0.83/0.25**

Table 3: The same as table 1 in Douala

Months	SUB (0000/1200 UTC)	NORM (0000/1200 UTC)	SUPR (0000/1200 UTC)	DUCT (0000/1200 UTC)
Jan	33/84	7594/8745	30/35	1/1
Feb	23/52	7836/8147	78/58	0/1
Mar	37/118	7656/8576	194/103	0/0
Apr	48/119	6476/6172	123/56	0/0
May	51/152	8501/8822	131/47	1/1
Jun	51/113	7804/8725	39/17	1/0
Jul	33/77	7921/8394	12/11	0/3
Aug	17/23	6685/6822	7/7	2/0
Sep	15/57	4727/5757	9/1	3/0
Oct	15/38	4973/5951	4/2	3/0
Nov	13/41	4726/5247	5/4	2/0
Dec	19/39	4401/5613	22/16	0/1
Mean	**29.58/76.08**	**6608.33/7247.58**	**54.50/29.75**	**1.08/0.58**

Tables 1, 2 and 3 depict the different refractive conditions and their number of occurrences at 0000 UTC and 1200 UTC from radiosoundings at Dakar (14.41°N, 17.26°W),

Douala (4.00°N, 9.70°E) and Niamey (13.35°N, 2.03°E). These tables show that normal refraction is the most frequently observed over these towns, followed by sub-refractive and super-refractive conditions. These stations were carefully selected to represent the various climatic regimes of West Africa. For example, Dakar is representative of the coastal climate while Douala is representative of the Guinea Gulf and Niamey of the Sahelian domain, respectively. The data cover the two main seasons of the years considered (i.e. the wet and dry seasons). Ducting situations are seldom observed over these three cities. Ducts represent the worst case of super-refraction and within them microwaves travel trapped like in a waveguide. To detect the AP features, a vertical resolution higher given by standard operational radiosonde data is desirable. The ability of the model to simulate the propagation conditions is overviewed in order to assess the feasibility of an operational diagnostic AP product. It should be noted that the increase in super-refraction from December to May in Dakar and Douala is mainly due to the high temperatures. In Niamey, super-refractive situations are observed between November and June.

Each table shows statistics calculated from the mean monthly statistical distribution of anomalous propagation (anaprop, hereafter) at each level. It shows that the monthly variation peaks around March corresponding to the high of the harmattan season characterized often with very cool nights and morning times and very dry day time. The vertical gradient of refractivity values drop gradually by the end of May and drastically between June and October corresponding to the period of rainy season. This can be associated with ground heat flux and the change of seasons which occurs in association with the meridional movement of the Inter-Tropical Discontinuity (ITD) which demarcates at the surface, the warm and moist (maritime) southwesterly trade winds from the hot and dry (continental) northeasterly winds leading to high temperature at the surface. There is however some observed days during the dry harmattan season of intensive temperature inversion especially in the morning hours and in the presence of large amounts of sand in the air. It was also observed that the absolute strength of ducts reduces while their variability increases inland.

By March the ITD has moved northward between 10°N and 12°N, exposing areas further south to heavy rainfall events. North of the ITD, the tropical continental air is still prevalent and conditions are still dry. During May and June, its position is 15 –16°N. There is widespread rain over areas south of 9 –10°N. Dakar, Douala and Niamey would have come under significant and appreciable amount of precipitation brought up north by the ITD. Lower temperatures and an increase in water vapor would cause an increase in refractivity values in the troposphere, hence higher gradients. After reaching its most northerly position of about 20°N in July, it then begins to migrate southwards in September, being pushed south by the tropical continental air mass, once more exposing areas north of 10–12°N to dry season conditions, subsequently lowering the dN/dz values.

Dakar (14.41°N, 17.26°W) is the capital and largest city of Senegal where the climate is generally warm. Dakar has semi-arid climate, with a short rainy season and a lengthy dry season. Dakar's rainy season lasts from July to October while the dry season covers the remaining eight months. The city sees approximately 495 mm of precipitation per year. Between December and May, Dakar is usually pleasantly warm with daily temperatures around 24-27°C. Nights during this time of the year are comfortable, some 17 - 20°C. However, between May and November the city becomes decidedly warmer with daily highs reaching 29-31°C and night lows a little bit above 23-24°C. Notwithstanding this hotter season Dakar's weather is far from being as hot as that of African cities inland, such as Niamey or N'Djamena, where temperatures hover above 36°C for much of the year. It has presumably the best climate in all western Africa, as it is cooled year-round with sea breezes. In Dakar (Tab.1) we have 86 and 107 AP at 0000 UTC and 1200 UTC, respectively. Of these, 37% at 0000 UTC (71% at 1200 UTC) were classified as sub-refractive, 61% at 0000 UTC (28% at 1200 UTC) super-refractive and 2% at 0000 UTC, (1% at 1200 UTC) as ducting layers. Only 28 days of the whole set experienced normal propagation in Dakar.

Niamey (2.03°E, 13.35°N) is capital of Niger with the population of 1.3 million in 2011. In Niamey the climate is hot semi-arid, with an expected rainfall of between 500 mm and 750 mm a year, mostly beginning with a few storms in May, then turning into a rainy season which usually lasts from sometime in June to early September, when the rains taper off rather quickly. Most of the rainfall is from late June to mid August. There is practically no rain from mid-October to April. Niamey is remarkably hot throughout the year. Average monthly high temperatures reach 38°C four months out of the year and in no month do average high temperatures fall below 32°C. We recorded for mean value 62 AP at 0000 UTC and 68 AP at 1200 UTC per month over Niamey (Table 2). It was found that the number of sub-refractive days was 299, super-refractive days 157 and finally the number of duct days was 11. Only 17 days of the whole set experienced normal propagation.

Douala (9.70°E, 4.00°N) is the economic capital of Cameroon. It had a population of about 2.5 million in 2012. Douala features a tropical monsoon climate, with relatively constant temperatures throughout the course of the year. The city typically features warm and humid conditions with an average annual temperature of 27.0°C and an average humidity of 85%. Douala sees plentiful rainfall during the course of the year, with an average of 3,600 mm precipitation per year. The driest month is December with only 28 mm of precipitation on average, while the wettest month is August with nearly 700 mm of rain on average. The weather is very hot and humid, which is characteristic of the coastal region in the Gulf of Guinea (Lenouo et al. 2009). About 100 km west of Douala is the active Mount Cameroon, with several summits reaching an altitude of 4100 m. In Douala (Table 3), we found that the number of sub-refractive days is 303, super-refractive days 209 and finally the number of duct days is 15. Only 9 days of the whole set had complete standard propagation (no anaprop). We noticed that anaprop occurrence is above 44% at 0000 UTC and 56% at 1200 UTC annually. Ducting generally is high in June, July, August, September, October and November which correspond to the long rainy season of this region. Douala, like many of the cities in southern Cameroon, is under the influence of a large quantity of moisture laden tropical maritime air resulting from the continuous migration of the intertropical front (Falodun and Ajewole, 2006). The anaprop occurrence increases in dry months from late November to May.

5-Conclusion

Climatological maps of occurrence of super-refraction and ducting layers have been constructed (Lopez, 2009). All of these results are consistent with the ducting statistics obtained from radio soundings over some cities in the West Africa (Falodum and Ajewole, 2006; Lenouo, 2012). One should remember that TLs with a base 3000 m above the surface are disregarded in this study. The midday (1200 UTC) is seldom affected by ducting as a result of the ceaseless and intense storm activity and the associated strong vertical mixing of the troposphere. In opposition, midnight, early morning are characterized by persistent ducting because of the combined effects of the trade wind temperature inversion and of the strong evaporation from the surface (sharp upward decrease of moisture inside the PBL). Over land, ducting events are generally less frequent at 1200 UTC than over the coastal area, with stronger seasonal variability, which includes the increase of turbulence inside the PBL and remains pronounced over moist regions in particular at the afternoon (1800 UTC).

The data used to calculate the refractivity index were obtained from in-situ measurements performed at the stations located at Dakar, Douala and Niamey from (January 2006 – December 2007). The measurement covered both climatic seasons (dry season and wet season) occurring in Dakar, Douala and Niamey every year. This study reveals that the anomalous propagation conditions are generally low during the rainy season (June – November). The winter (DJF) and spring (MAM) are dominated by the dry harmattan and the number of observed anaprop increases sharply. Sub-refractive conditions prevail at 1200 UTC all year round. Super-refractive conditions and ducting conditions are observed at 0000 UTC. The daily temperature differences during the afternoon and early-morning hours amplify the effects of sea and land breezes over Dakar and Douala as shown in Critchfield (1983). In addition to the influence of sea breezes, convective motions resulting from the daytime heating act to increase the wind speed (Mentes et al. 2001; Onol 1998), which leads to an enhanced moisture transfer from the sea to the land. In weather applications, ducting was shown to give rise to coverage fades, range–height errors, false echoes, and scattered and anomalous clutter returns to the radars and acoustic sounders (Abdul-Jauwad et al. 1991; Skura 1987; Gossard 1977). If not removed, the false radar echoes may lead to erroneous rainfall estimations and even the forecast of fictitious floods (Moszkowicz et al. 1994). At this time, although a complete long-term climatological study is missing, these results serve as a basis for future comprehensive and comparative studies of atmospheric refractivity for the West Africa region.

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