Effect of Atmospheric Refraction on Wave Propagation with Variations based on Geographical Location in Tropical Environments

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Abstract- Air masses in the atmosphere have contrasting temperature, humidity and moisture, which influence radio signals traversing the atmosphere. This atmospheric variability influences radio wave propagation in the atmosphere, which is often conveniently described by the radio refractive index. The changes in the refractive index in the troposphere determine the nature of the radio wave propagating through it. This paper studies radiosonde data and investigates their dynamic effect on radio wave propagation. The study established that refractivity could be used as a measure of diurnal radio wave degradation.

Keywords – Atmosphere, Degradation, Radiosonde, Refractive index and Signal

I. INTRODUCTION

The current cost of performing radiosonde measurements limits the optimum spacing of the operational radiosonde network to 250 km in the horizontal direction [WMO-ITU, 2009]. From the radiosonde measurements, the air refractive index can be estimated. The changes in the refractive index of air in the troposphere determine the nature of the radio-wave propagation. Multipath effects arise due to large scale variations in atmospheric radio refractive index, such as horizontal layers with very different refractivity [Grabner and Kvicera, 2003]. This effect becomes noticeable, when the same signal takes different paths to its target and the rays arriving at different times thereby interfering with each other during propagation through the troposphere. The consequence of this large-scale variation in the atmospheric refractive index is that radiowaves propagating through the atmosphere becomes progressively curved towards the earth. Thus, the range of the radiowaves is determined by the height dependence of the refractivity. Therefore, the refractivity of the atmosphere will not only affect the curvature of the ray path but will also provide some insight into the fading of radio waves through the troposphere [Adediji and Ajewole, 2008]. In the planning and design of microwave communication links, the structure of the radio refractive index in the lower part of the atmospheric boundary layer is very important. The refractive property of the neutral atmosphere is related to pressure, temperature and water vapor partial pressure. Troposphere—the lowest part of the atmosphere that extends from the earth surface up to about 10 km—is a non-dispersive medium and its refraction effect estimation is possible only by modeling the tropospheric medium. The atmospheric parameters like pressure, temperature and water vapor undergoes variations based on the geographical locations and seasons. The first step is to estimate the refractivity of the atmosphere. The refractive index of the neutral atmosphere is related to atmospheric parameters as [Thayer, 1974; Liebe *et al.*, 1977].

$$N = (n-1)10^6 = k_1 \frac{P}{T} + k_2 \frac{e}{T} + k_3 \frac{e}{T^2} \qquad (1)$$

where N is termed as refractivity, T is temperature (K), e is the water vapour (unitless) and P is the hydrostatic atmospheric pressure (in hPa). The constants k1, k2 and k3 have values 77.6848, 71.2952 and 375463 respectively (Rüeger, 2002). These are found to be valid for the estimation of N for frequency up to 30 GHz and for normally encountered ranges of pressure, temperature and humidity. The tropospheric refractivity given by (1) consists of two parts [Saastamoinen, 1972]: one the hydrostatic component or dry component (ND)—represented by and the other non-hydrostatic component or wet component (Nw)—represented by

$$\left\{ N_D = k_1 \frac{P}{T} \right\}$$

$$\left(N_w = k_2 \frac{e}{T} + k_3 \frac{e}{T^2} \right)$$

The dry gases in the troposphere like N2, O2, etc., contribute for hydrostatic component while water vapour causes primarily the wet component [Davis et al., 1985]. The water vapour is mostly confined to lower part of troposphere and shows significant temporal and spatial variability, while the variability of P and T is well defined. The water vapour pressure e is usually calculated from the relative humidity, and saturated water vapour, using the expression [Adediji *et al.,* 2007].

$$e = 0.061121 H \exp\left\{ \frac{17.502t}{t + 240.97} \right\} \tag{2}$$

where H = relative humidity (%), and t = temperature (in deg C).

These tropospheric factors—such as variations of radio refractive index and its “normal” change with height—enable radio-wave propagation over a greater than line-of-sight range. This effect was taken into approximate account by assuming an increased radius for the Earth, e.g. by a factor of 4/3 as in Longley-Rice model [1968]. The Longley-Rice model [1968] is simple calculation: it uses the horizontal difference, but neglects the vertical section information, therefore not accurate [Zullang et al., 2008]. Moreover temperature inversions can cause ducting, with relatively low attenuation over large distances beyond the horizon. A related magnitude is the modified refractivity M, which is defined as

$$M = N + \frac{z}{r_g} \tag{3}$$

where z is altitude (km) and rg is the geometric radius due to the elliptical nature of the Earth's orbit (in km). The geometric radius rg depends on the latitude/longitude of the region under consideration; specifically at any particular longitude, as [Kolawole, 2010]

$$r_g \approx r_e \left(0.99832 + 0.001684 \cos 2\theta_{lat} - 0.000004 \cos 4\theta_{lat} \cdots \right) \tag{4}$$

where re is the radius of the earth at the equator (in km).

To characterize electromagnetic propagation conditions with respect to the earth's curvature often the gradient dM/dz is used. As the modified refractivity M is a measure of the meteorological parameter air pressure p, air temperature T, water vapour e, radio propagation refractivity conditions may be characterized by the gradients of these parameters:

$$\frac{dM}{dz} = \frac{\partial M}{\partial p}\frac{dp}{dz} + \frac{\partial M}{\partial T}\frac{dT}{dz} + \frac{\partial M}{\partial e}\frac{de}{dz} \tag{5}$$

The effect of modified refractivity M is to characterize propagation conditions factoring the curvature of the ray path along the Earth's surface. When characterizing the radio propagation environment, it is natural to consider the vertical refractivity gradient of the air of the first kilometre above the ground level to estimate propagation effects such as ducting, surface reflection and multipath on terrestrial line-of-sight links. The dependence of refractivity on the physical structure of the atmosphere implies that changing meteorological conditions can lead to changes in radiowave propagation. This paper uses meteorological measurements to investigate the impact of these meteorological structures on radio-wave propagation.

II. DATA ANALYSIS

There is a wide range of variations in the climate of Nigeria. It ranges from the typical thick rain forest to sahel savannah type peculiar to the tropics. Hence the modelling of selected cities that cut across those ranges within the tropics. In order to model, the meteorological data for different locations were collected over a period of six years (i.e. 2000 and 2005). The selected locations are Abuja (Long 07 00’E, lat 09 15’N), Jos (Long. 08o 51’E, Lat 9o 38’N) and Maiduguri (Long 13o 05’E, Lat 11o 51’N). Radiosonde data were collected by, and obtained between year 2000 and 2005 from, the Nigerian Meteorological Unit (NIMET) for a given location and time were used to determine the corresponding refractivity profile for these cities. The study areas are within the 250km-axis recommended by WMO-ITU (2009) for operational radiosonde network for successful extrapolation and interpretation for communications operations.

III. RESULTS AND DISCUSSIONS

The data covered year 2005-2010, and the seasons\ representative periods were modelled; that is, the harmattan season (December), dry season (March) and the rainy season (August). The analysis of the data was carried out, and the diurnal mean and standard deviation of 366.40 and 1.506 were obtained respectively. This was substantiated with the expressions in equation 3—the modified refractivity where altitude (km) and the geometric radius due to the elliptical nature of the Earth's orbit (in km) were included. Then error was found to be marginal, about 0.2%.

The close study of all the figures 1, 2, and 3, showed that the refractivity is generally high during the wet seasons in all the three models. However the value falls sharply in March as against December (Harmattan). Normally, Jos is at higher altitude, and is very cold in December (sometimes with some elements of ice flakes), so the water vapour will be high around that period, but as for March, it will be very hot. In the case of Maiduguri, it is very hot, more of savannah. This explains the crossing of the profile in Fig 3 of December/March. The three cities seasonal profiles showed that within the period of 12hr and 15hr, there is depression in the responses; an indication of the effect of temperature, which may indicate that a considerable amount of attenuation may have been removed.

In all the profiles, there is a considerable difference between the non-wet and wet seasons’ refractivity. This might be due to the dry particulates being absorbed as condensates or just washed away. A representative profile of the post-rain refractivity, shown in fig 4, demonstrates wavy-response, which may point to corresponding level of signal degradation. Multiple-path reflection and/or refraction would have been imposed by the dry particulates resulting in drastic reduction in their refractivity. As a consequence, it could be deduced that towns at the same longitude, but not necessarily of the same latitude would have varied refractive properties dictated by the water component in the atmosphere.

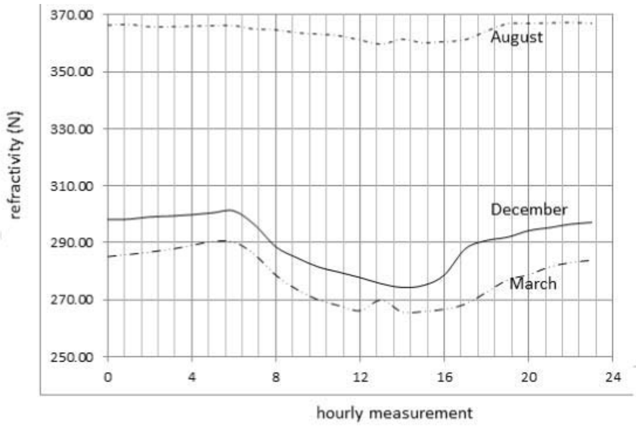

Figure 1. Representative seasonal-hourly refractivity for Abuja, Nigeria

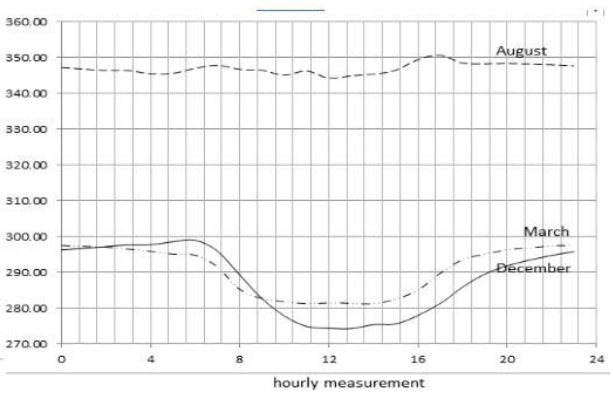

Figure 2. Representative seasonal-hourly refractivity for Jos, Nigeria

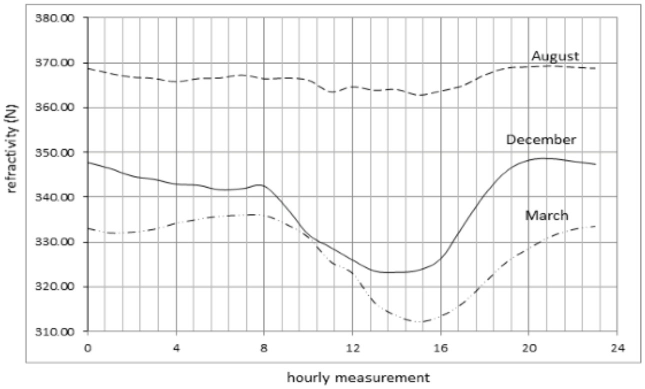

Figure 3. Representative seasonal-hourly refractivity for Maiduguri, Nigeria

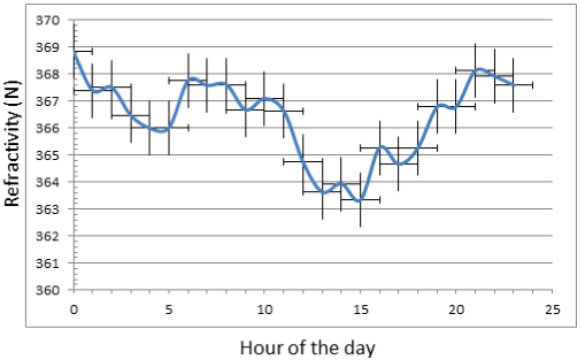

Figure 4: Representative profile of post-rain refractivity with 1-standard deviation error bar

IV. CONCLUSION

The somewhat limited results reported here demonstrate the dependence of refractivity on the physical structure of the atmosphere. This implies that changing meteorological conditions can lead to changes in radio wave propagation. The study suggests that similar trends as refractivity could serve as expected fluctuation in propagation signal losses when subjected to similar atmospheric conditions measured by meteorologists. We are currently pursuing this objective and the results will be reported elsewhere.

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