



Determination of Refractivity Gradient and Geoclimatic Factor Using Radiosonde Data and Inverse Distance Weighting Spatial Interpolation for Missing Data

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Abstract: In this paper, point refractivity gradient and geoclimatic factor are determined using radiosonde data on meteorological parameters obtained in Calabar, Nigeria. The meteorological parameters used are air temperature, pressure and humidity obtained from the radiosonde data archive of Nigerian Meteorological Agency. In view of the poor spatial resolution of radiosonde data, inverse distance weighting spatial interpolation technique is used to obtain the missing data at certain height of interest in the study. The results obtained showed that the point refractivity gradient and geoclimatic factor showed monthly and seasonal variations. Specifically, Calabar has annual average Point Refractivity Gradient (dN) and Geoclimatic Factor (K) of -125.508 N-units/Km and 6.53762E-05 respectively. The largest dN value of -25.4683 N-units/Km occurred in May whereas the smallest value of -305.2692 N-units/Km occurred in November. Furthermore, there is higher value of point refractivity gradient in the rainy season than in the dry season whereas there is lower value of geoclimatic factor in the rainy season than in the dry season.

Keywords: Refractivity Gradient, Geoclimatic Factor, Inverse Distance Weighting Spatial Interpolation, Clear-Air Fading Mechanism, Multipath Fading, Spatial Interpolation

1. Introduction

In recent times, the concept of wireless communication in the lower atmospheric layer has become very essential to radio communications due to increasing demand for such technologies [1, 2, 3]. The wide spread application is brought about by the sophistication and ever changing trend of radio communication. However, due to the enormous demand and wide spread applications of wireless communications, there is the need to look closely into those properties which contribute to fading during signal propagation [4]. Considering signal transmission under clear air condition, especially on terrestrial line of sight links, several atmospheric actions leads to signal losses on the transmission link [5, 6, 7, 8]. Clear-air fading mechanism due to extreme refractive layers in the atmosphere includes beam spreading, antenna decoupling, surface multipath and atmospheric multipath [9]. In the terrestrial line of sight link, it has been shown that multipath fading is among

the most recurring fading phenomenon in tropospheric propagation [10].

Importantly, geoclimatic factor is one of the factors used in the determination of the multipath fade depth at any point in radio communication link [9, 10]. Geoclimatic factor determination is primarily based on the use of meteorological parameters obtained in the lower atmosphere. The meteorological parameters used are mostly, temperature, pressure, humidity and vapour pressure. These parameters affect the propagation of electromagnetic waves in the lower part of the atmosphere. To characterize the effect of the meteorological parameters, an index named the radio refractive index n is used [12]. The radio refractive index n is further related to radio refractivity (N) and hence, radio refractivity gradient (dN) as well as geoclimatic factor (k) that is used in the determination of multipath fade depth at any point in radio communication link.

In this paper, the focus is to determine point refractivity

gradient and geoclimatic factor using radiosonde data on meteorological parameters obtained in Calabar. Calabar is the major city in cross River state located in the South South part of Nigeria. The geo-coordinates of Calabar is 4.9757° N Latitude and 8.3417° E longitude. Calabar has two different seasons, the rainy and the dry seasons. The rainy season occurs April to September whereas the dry seasons occur October to March. In some cases, Calabar witness rainfall during the dry season because it is surrounded by rivers and the Atlantic Ocean [13]. The study will also examine the temporal variations in the values of point refractivity gradient and geoclimatic factor for Calabar.

2. Theoretical Background

The concept of geoclimatic factor estimation remains vital to radio link planners as it is one of the major parameters in fade depth determination. The geoclimatic factor is used to determine the worst month outage probability [14, 15, 16]. Geoclimatic factor estimation is based on the refractivity gradient (dN), which is a function of some atmospheric parameters such as temperature, pressure and atmospheric vapour pressure. The refractivity gradient from study varies with atmospheric height, and also has seasonal and annual variation due to region and other parameters such as air humidity, pressure and so on. In order to take into account the variation of the atmospheric state as the values of the meteorological parameters change, the ITU-R recommends using the following parameters: the atmospheric radio-refractive index, the refractivity gradient, the point refractivity gradient and geoclimatic factor to design the communication link [17]. However, the refractivity at the lowest 65m from sea level can be computed by [18].

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

Where e stands for water vapour pressure (in hpa) where [9]:

$$e = \frac{6.112 H}{100} \exp \left(\frac{17.5 t}{t + 240.97} \right) \quad (2)$$

H is the relative humidity (%)
t is the air temperature (Kelvin)

The value of N varies with attitude since all of the climatic parameters, namely, relative humidity, temperature and pressure vary with height.

Also, it is important to consider the point refractivity gradient which the geoclimatic factor is dependent upon. The vertical gradient of radio refractivity in the lowest layer of the atmosphere is an important parameter for the estimation of path clearance and propagation effects such as ducting, surface reflection and multipath on terrestrial line of sight lines. The refractive gradient at the upper atmosphere is calculated by [19].

$$\frac{dN}{dh} = \frac{N_2 - N_1}{h_2 - h_1} \quad (3)$$

Where

N_1 is the lower atmospheric refractive index
 h_1 is the lower height (ground level),
 N_2 is the upper atmospheric refractive index and
 h_2 is upper height (65m).

$\frac{dN}{dh}$ can be represented as dN1. Hence, the geoclimatic factor for quick planning can be calculated from the approach given by International Telecommunication Union [20, 21];

$$K = 10^{-4.6 - 0.0027 \text{ dN1}} \quad (4)$$

3. Methodology

In this work, three years data on meteorological parameters, namely, air temperature, pressure and humidity are obtained from Nigerian Meteorological Agency (NIMET). The NIMET meteorological parameters data are obtained using radiosonde, which is an radiosonde is an airborne weather station with inbuilt radio transmitter. The radiosonde is launched on daily basis and as it ascends from ground level it measures the meteorological parameters at given time interval. At the same time, it transmits the measured values to the appropriate ground station where the data are further processed [14]. Notably, radiosonde do not measure and report climatic parameters at definite heights, rather it measures at preset time intervals. Due to the spatial resolution problem in the radiosonde data obtained, Inverse Distance Weighting (IDW) technique is used for interpolation of the radiosonde data to obtain the missing data at specific heights required in the study. The IDW technique is expressed as [22, 23]:

$$\hat{Z}(x_0) = \sum_{i=1}^n \{ (\lambda_i) Z(x_i) \} \quad (5)$$

Where

\hat{Z} is the approximated value at the point of interest x_0 ,

Z is the known value at the sampled point x_i ,

λ_i is the weighting parameter and

n denotes the number of sampled points used for approximation.

The weighting bias (λ_i) in equation 6 can be represented by as,

$$\lambda_i = \frac{\frac{1}{(d_i)^p}}{\sum_{i=0}^{i=n} \left(\frac{1}{(d_i)^p} \right)} \quad (6)$$

Where

d_i is the distance between x_0 and x_i ,

p is a power parameter, and n is as denoted previously.

The IDW technique is applied in the spatial interpolation of the radiosonde data on air temperature (Temp), pressure (Pres) and humidity (Humd) as follows;

Let x_i be the height at the time i at which the radiosonde took the i^{th} reading of temperature ($\text{Temp}(x_i)$), pressure ($\text{Pres}(x_i)$) and humidity ($\text{Humd}(x_i)$)

Let x_0 be the height of interest. Particularly, 65m is one of the height the value of the temperature, pressure and humidity are required.

Let $\text{Temp}(x_0)$, $\text{Pres}(x_0)$ and $\text{Humd}(x_0)$ be the approximated value of air temperature, pressure and humidity

at the point of interest x_0 . Then,

$$d_i = x_0 - x_i \quad (7)$$

A value of 2 is taken for p . Then, for all $i = 1, 2, 3, \dots, n$ the value of d_i and λ_i are computed. Also, for each i , equation 6 is used to compute the value of $\text{Temp}(x_0)$, $\text{Pres}(x_0)$ and $\text{Humd}(x_0)$ as follows;

$$\text{Temp}(x_0) = \sum_{i=1}^n \{(\lambda_i) \text{Temp}(x_i)\} \quad (8)$$

$$\text{Pres}(x_0) = \sum_{i=1}^n \{(\lambda_i) \text{Pres}(x_i)\} \quad (9)$$

$$\text{Humd}(x_0) = \sum_{i=1}^n \{(\lambda_i) \text{Humd}(x_i)\} \quad (10)$$

After determining the values of air temperature, pressure and humidity at all the essential heights, including, 65m, the water vapour pressure (e) and the radio refractivity (N) are computed using equation 2 and equation 1 respectively. Next, the point refractivity gradient ($\frac{dN}{dh}$) in the lowest 65m altitude of the atmosphere is calculated using equation 4 by setting $h_1 = 65$ m and $h_2 = 0$ m. Finally, the geoclimatic factor (K) is obtained using equation 5.

4. Results and Discussion

The results of the computations for the monthly Point

Refractivity Gradient (dN) and Geoclimatic Factor (K) for Calabar are given in Table 1, Figure 1 and figure 2. According to table 1, the annual average Point Refractivity Gradient (dN) and Geoclimatic Factor (K) for Calabar are -125.508 N-units/Km and 6.53762E-05 respectively. There is wide variation in the value of point refractivity gradient in Calabar; the largest value of -25.4683 N-units/Km occurred in May whereas the smallest value of -305.2692 N-units/Km occurred in November.

Table 1. Monthly Point Refractivity Gradient (dN) and Geoclimatic Factor (K) for Calabar.

Month	dN (N-units / Km)	Geoclimatic Factor (K)
Jan	-33.002	3.08393E-05
Feb	-74.363	3.98822E-05
Mar	-256.57	0.000123801
Apr	-111.33	5.01867E-05
May	-25.468	2.94282E-05
Jun	-75.53	4.01726E-05
Jul	-38.643	3.19401E-05
Aug	-75.601	4.01905E-05
Sep	-92.515	4.46469E-05
Oct	-186.86	8.02622E-05
Nov	-305.27	0.000167582
Dec	-230.96	0.000105583
Annual Average	-125.508	6.53762E-05

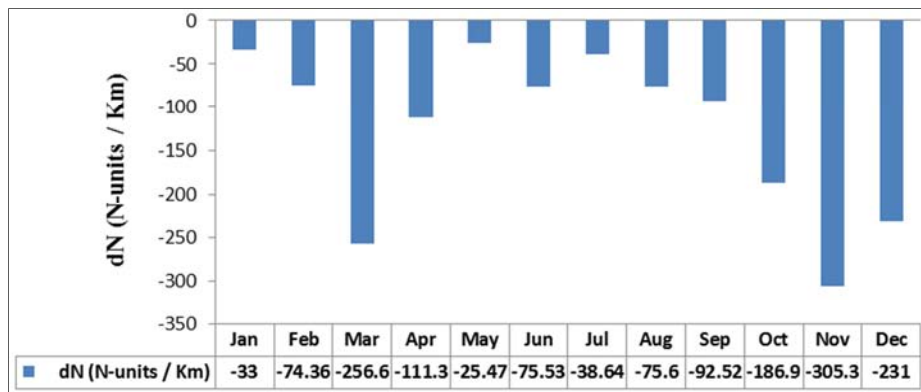


Fig. 1. Point Refractivity Gradient (dN) for the various months of the year.

Conversely, the variation in the value of geoclimatic factor in Calabar (table 1 and figure 2) is such that the largest value

of 0.000167582 occurred in November whereas the smallest value of 2.94282E-05 occurred in May.

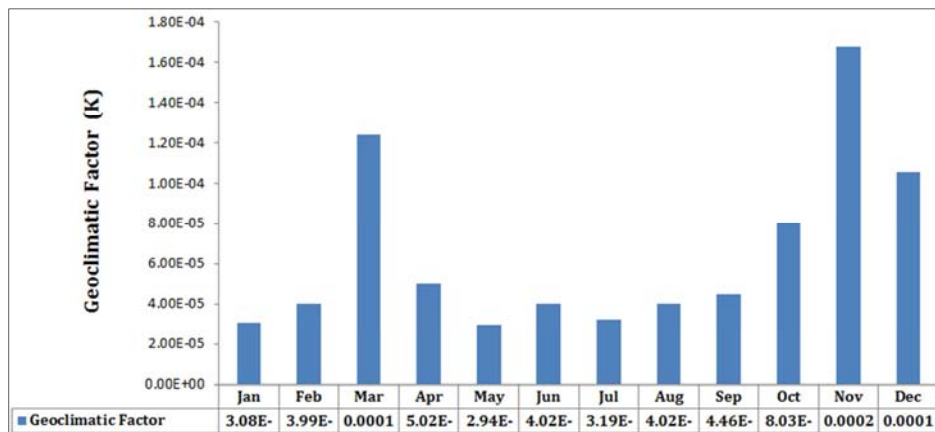


Fig. 2. Geoclimatic Factor (K) for the various months of the year.

There are also seasonal variations in the values of dN and K for Calabar, as shown in Table 2, Figure 3 and Figure 4. Notably, in Calabar the rainy season occurs April to September whereas the dry seasons occurs October to March (Ele and Nkang, 2014). In Figure 3, the rainy season average dN is -69.8478333 (N-units / Km) whereas the dry season average dN is -181.1708333 (N-units / Km). Essentially, the point refractivity gradient (dN) is higher in the rainy season than in the dry season.

On the contrary, in Table 2 and Figure 4, the rainy season average Geoclimatic factor (K) is $3.94275E-05$ whereas the dry season average Geoclimatic factor (K) is $9.1325E-05$. As such, the Geoclimatic factor is higher in the dry season than in the rainy season.

The distribution shows lower values in the rainy period between May and September while higher values occur in dry season with November having the highest.

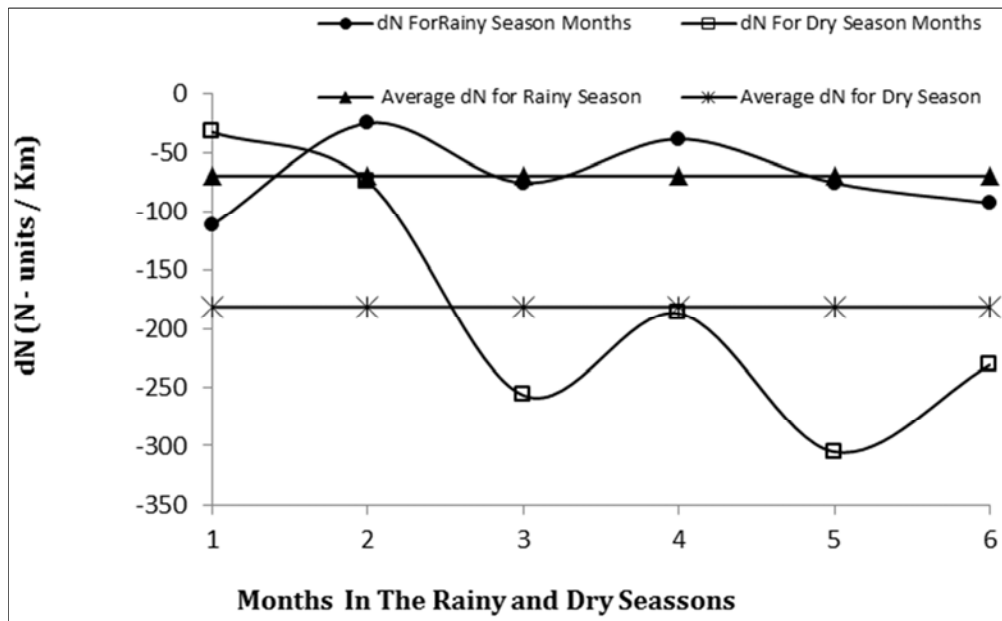


Fig. 3. dN for the Rainy and Dry Seasons Months In Calabar.

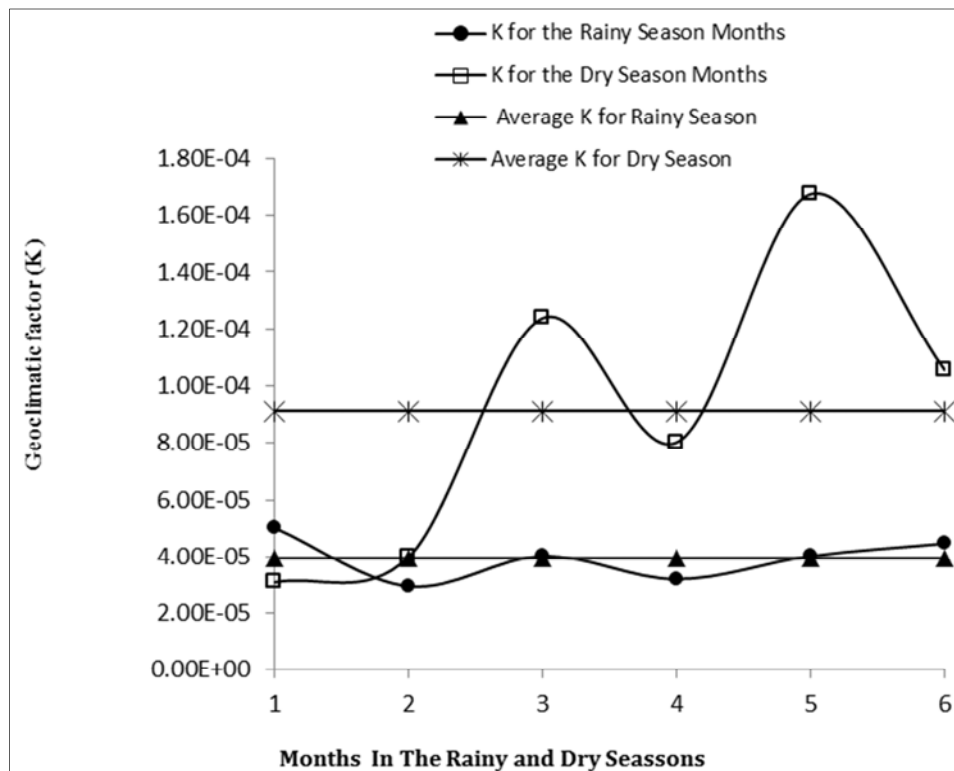


Fig. 4. Geoclimatic factor (K) for the Rainy and Dry Season Months In Calabar.

Table 2. Point Refractivity Gradient (dN) for the Rainy and Dry Seasons Months In Calabar.

Rainy Season Months		dN (N-units / Km) For The Rainy Season Months	Dry Season Months		dN (N-units / Km) For The Dry Season Months
1	Apr	-111.33	Jan		-33.002
2	May	-25.468	Feb		-74.363
3	Jun	-75.53	March		-256.57
4	Jul	-38.643	Oct		-186.86
5	Aug	-75.601	Nov		-305.27
6	Sep	-92.515	Dec		-230.96
Average dN (N-units / Km) For Rainy Season Months		-69.84783333	Average dN (N-units / Km) For Dry Season Months		-181.1708333

Table 3. Geoclimatic factor (K) for the Rainy and Dry Season Months In Calabar.

Rainy Season Months		Geoclimatic factor (K) for the Rainy Season Months	Dry Season Months		Geoclimatic factor (K) for the Dry Season Months
1	Apr	5.02E-05	Jan		3.08E-05
2	May	2.94E-05	Feb		3.99E-05
3	Jun	4.02E-05	March		0.000123801
4	Jul	3.19E-05	Oct		8.03E-05
5	Aug	4.02E-05	Nov		0.000167582
6	Sep	4.46E-05	Dec		0.000105583
Average Geoclimatic factor (K) for the Rainy Season Months		3.94275E-05	Average Geoclimatic factor (K) for the Dry Season Months		9.1325E-05

5. Conclusions

Point refractivity gradient and geoclimatic factor are determined using radiosonde data on meteorological parameters, namely, air temperature, pressure and humidity obtained in Calabar. The point refractivity gradient and geoclimatic factor showed monthly and seasonal variations. There is higher value of point refractivity gradient in the rainy season than in the dry season whereas there is lower value of geoclimatic factor in the rainy season than in the dry season.

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