Geoclimatic Factor and Point Refractivity Evaluation in Quebec-Canada

***Yamina Bettouche*[1]*, Basile L. Agba**[2]*, and Ammar B. Kouki*[1]**

[1]École de Technologie Supérieure, 1100, rue Notre-Dame Ouest, Montréal, Québec, Canada H3C 1K3

[2]Institut de Recherche d Hydro-Québec, 1800 Lionel-Boulet, Varennes, Québec, Canada J3X 1S1

Yamina.bettouche.1@ens.etsmtl.ca, agba.basile@ireq.ca and ammar.kouki@etsmtl.ca

Abstract

It is well known that the propagation of electromagnetic waves is affected by the refractivity of the atmosphere. This refractivity is characterized by the value of the radio refractive index, which depends on the temperature, pressure, and humidity in the atmosphere. In this paper, we estimate the radio refractive index (N), the point refractivity gradient (dN_1) as well as, the geoclimatic factor (K) at altitude 65 m above the ground based on the radiosonde meteorological data in the coastal north-east station, Spet-iles (Quebec), at latitude 50.22°N and longitude 66.27° W, with altitude of 52 m above mean sea level from 2009 to 2013. These data have been obtained from NOAA/ESRL [1] Earth System Research Laboratory database. The average values of daily, monthly and seasonal variations of the dN_1 and K are analysed for a given year. Thereafter, the obtained average annual values of the dN_1 and K for several years are compared with the values obtained from the ITU-R world map.

1. Introduction

The atmosphere is mainly characterized by temperature, pressure, humidity, and vapor pressure [1, 2, and 3]. These parameters affect the propagation of electromagnetic waves in the lower part of the atmosphere (troposphere). To quantify this effect, an index named the radio refractive index, n is used [1]. Thus, the knowledge of the structure of the index n is very important to the design of the communication links.

A standard radio atmosphere is defined as an atmosphere having the standard refractivity gradient. A standard value of vertical gradient of refractivity used in refraction studies is around 40 N/km. This corresponds approximately to the median value of the gradient in the first kilometre of altitude in temperate regions [4]. Under these conditions, the value of the index n is near unit. In certain cases, the value of the index n may decrease. The decrease of the index n will curve the path of the propagating wave [5, 6, 7, 8, 9, 10 and 11], which results in multipath propagation. In practice, the change of index n is very low and can be difficult to have an accurate measure of its variation. Nevertheless, this change degrades considerably the transmission of radio wave. For this reason, it is preferable to use another index which variation will be appreciable in comparison with the variation of the index n. This index is the refractivity, denoted by N [9, 12, and 13]. A second abnormal phenomenon, which can occur during the propagation of the electromagnetic waves, is bending [1] (Bending waves are surface waves which appear in thin media. The thickness of the media is small compared to the wavelength [14]). The index N is good to characterize the curving of the electromagnetic waves, but not the bending phenomena. The gradient of the radio refractive index, G [2, 9] is the index used to characterize the bending of electromagnetic waves.

According to the ITU-R-P-530 recommendation, the geoclimatic factor is used to determine the worst month outage probability. The estimation of this factor is based on the refractivity gradient, dN_1, which is a function of temperature, pressure, humidity, and vapor pressure and shows a seasonal variation of the refractivity gradient [6]. It has been noted that the gradient has a high value during the rainy season. This can be attributed to the air humidity in this season. Many studies are conducted in different regions. In [5], the authors study the geoclimatic factor in South Africa and Botswana. The authors in [8] analyze year to year variations of the mean refractivity gradient in the gulf region. In [9], the analysis of dependency of average value of the radio refractivity in different time of day in Vilnius is reported. Authors in [10] show that the values of the radio refractive index obtained using local climatic data differ from the average data obtained close to the ground surface.

The main contribution of this paper is the determination of the mean values of daily, monthly, seasonal variations of the radio refractive index, point refractivity gradient, and geoclimatic factor in Quebec, Canada based on the radiosonde meteorological data from 2009 to 2013. These data have been obtained from NOAA/ESRL. The second contribution is the comparison of the annual values of dN_1 for several years with the value obtained from the ITU-R word map.

2. Theory

The atmosphere is characterized by the values of the meteorological parameters (air temperature, pressure, humidity and vapor pressure). These parameters change during day and depend on the height above the sea level (ASL) [6]. The variation of the atmosphere state affects the propagation of the radio electromagnetic waves. In order to take into account the variation of the atmosphere 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

[1] National Oceanic and Atmospheric Administration (NOAA), Earth System Research Laboratory (ESRL)

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refractivity gradient and geoclimatic factor to design the communication links [7]. In the rest of this section, the analytical formula to calculate each parameter is given.

2.1 Radio refractivity

The atmospheric radio-refractive index is determined by the following formula: [5, 13]

$$n = 1 + N \times 10^{-6} \tag{1}$$

where: *N is the radio refractivity expressed by*

$$N = \frac{77.6}{T}\left(P + 4810 \times \left(\frac{e}{T}\right)\right) \tag{2}$$

where: *P is the atmospheric pressure (hpa), T is the absolute temperature (K), e is the water vapour pressure (hpa).* According to [8, 16] , the water vapour pressure can be determined approximately as follows:

$$e = 6.11 \times 10^{\left(7.5 t_d / 237.7 + t_d\right)} \tag{3}$$

The equations (1, 2) may be used for all radio frequencies; for frequencies up to 100 GHz, the error is less than 0.5 %. [13]

2.2 Refractivity gradient

The refractivity gradient, dN/dh indicates how the radio refractivity index varies as the height (ASL) increases. It can be obtained from surface refractivity and refractivity at any height within the 1 km layer above the ground level (AGL), using the following linear equation [7, 8, 9 and 6]

$$\frac{dN}{dh} = \frac{N_2 - N_1}{h_2 - h_1} \tag{4}$$

where N_1 and N_2 are the refractivity at heights h_1 (m) and h_2 (m).
Based on [5], the equation (4) becomes:

$$\frac{dN}{dh} = 77.6 \frac{1}{T}\frac{dP}{dh}\left(\frac{77.6P}{T^2} + \frac{746512e}{T^3}\right)\frac{dT}{dh} + \frac{373256}{T^2}\frac{de}{dh} \tag{5}$$

From formula (5), it is clear that the refractivity gradient is proportional to the gradient of the following meteorological parameters: pressure (P), temperature (T), and water vapor (e). The field analysis show that the propagation effects such as multipath, reflection, and ducting are mainly determined by the vertical refractivity gradient in the lowest 100 m. ITU-R recommends using the point refractivity gradient in the lowest 65 m of the atmosphere not exceeded for 1% of an average year [5, 12]. The gradient at this height is denoted by dN_1. The value of dN_1 is obtained using (4), where N_s is calculated considering the h_s value nearest to 65 m.

2.3 Geoclimatic factor

An accurate procedure to determine the geoclimatic factor can be found in [12]. In this paper, we will use the following approximate formula:

$$K = 10^{-4.6 - 0.0027 dN_1} \tag{6}$$

where: *dN_1 is the point refractivity gradient in the lowest 65 m of the atmosphere not exceeded for 1% of an average year* [12].

3. Methodology

The estimation of parameters N, dN_1, and K is based on the values of the meteorological parameters (pressure, temperature, dewpoint temperature). The meteorological parameters are obtained from radiosonde. A radiosonde is an airborne weather station equipped with a radio transmitter. This transmitter measures meteorological parameters at given frequency rate and/or height (ASL). The measured parameters are sent to an appropriate station for further processing [17].

The methodology used to determine the appropriate parameters consists of the following main steps:

1. *Determine the radio refractivity, N according to (2)*
2. *Determine the radio refractivity, at altitude 65 m.* If the radiosonde data in the nearest of the altitude 65 m are available, then the value of N is obtained from (2) considering that: 60 m < h_1 < 70 m. Otherwise, the variation of the metrological parameters is negligible. In this case, the value of the N_1 is estimated considering that $h_1 = 0$.
3. *Determine the point refractivity gradient in the lowest 65 m of the atmosphere, dN_1 (N-units / Km).* The value of dN_1 is determined from equation (4) setting $h_1 = 65$ m, $h_2 = 0$ m.
4. *Determine the geoclimatic factor, K according to (5).*

4. Methodology

The methodology described in section 3 of this paper has been used to estimate the radio refractivity in Sept-îles (Quebec). The meteorological parameters, particularly the pressure, temperature and relative humidity have been provided by NOAA/ESRL Earth System Research Laboratory database. The refractivity is estimated based on Equation (2) from the recorded meteorological parameters. The water vapour pressure (e) is derived from the recorded temperature value by using Equation (3). The average daily, monthly, and seasonal variations of dN_1 are shown on figures 1, 2, and 3 respectively. From figure 2, it can be seen that the monthly variations of dN_1 oscillate between -6080 and 10 N/km. During summer (May to August) the values of dN_1 are lower in comparison to the same values in winter (December to January). The cause of this difference is attributed to the variations of the metrological parameters and to the increasing temperature with the height.

4.1 Daily variation of dN_1

The recorded meteorological data for Sept-îles in 2013 have been used to determine the daily variations of the radio refractivity in each month. Figure 1 shows the average daily variation values of the radio refractivity in Sept-iles for all seasons of 2013. Analysis of the data shows that the values of the radio refractivity vary from day to day.

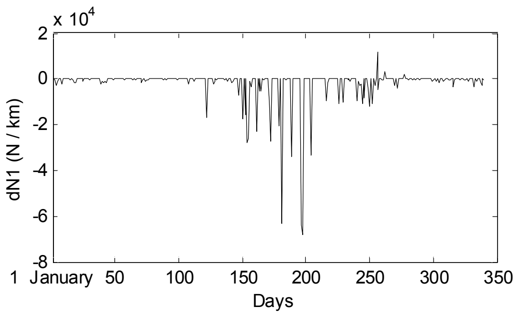

Fig. 1. Daily variation of radio refractivity in Sept-iles on 2013

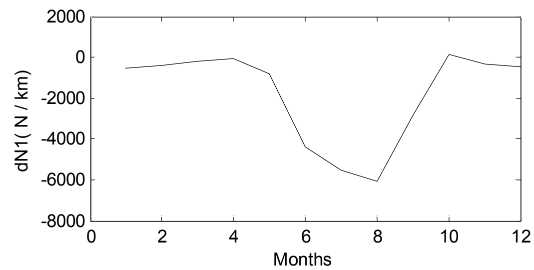

Fig. 2. Monthly variation of dN_1 value of the radio refractivity gradient in Sept-îles on 201

4.2 Monthly variation of dN_1

Figure 2 shows the mean monthly vertical gradient of refractivity calculated on the basis of the daily vertical gradient of refractivity at each month. It shows that the monthly variation vary between -507 and 10 N/km from January to April and from September to December. We note December 2013 was colder than normal across Quebec [18]. The values decrease gradually from May to June, and then drastically from July to August. These last months correspond to summer season characterised by very warm and very dry day time [18].

From figure 2 we note that in May and September, the values of dN_1 are significantly higher than the values in other months. This is because in May and September, the air temperature is high and air is more humid in Sept-iles. These observations confirm the results obtained in [9]. Table 1 shows the average monthly variation of the geoclimatic factor. From Table 1, we note a monthly variation of the geoclimatic factor.

K	January	February	March	April	May	June
2013	5.87E-04	2.69E-04	7.61E-05	1.37E-05	4.20E-05	1.12E-05
	July	August	September	October	November	December
	NaN	1.85E-04	1.14E+03	1.12E-05	1.85E-04	4.67E-04

Table 1. Monthly variation of K

4.3 Seasonal variation of dN_1

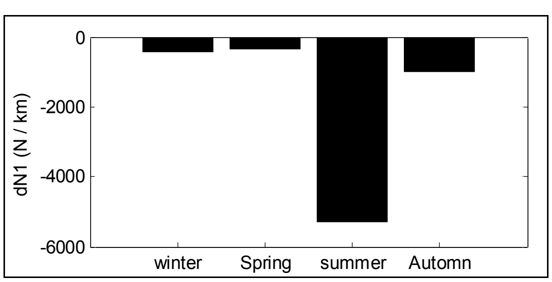

Fig. 3. Seasonal variation of dN_1.

	The point of refractivity gradient, dN_1	
	ITU value	Obtained values
2013	-273.2	-1786.2
2012		-2732.7
2010		-1834.5
2009		-1815.7

Table 2. dN_1 compared with ITU map

Figure 3 shows the mean of seasonal vertical gradient of refractivity. The values are estimated based on the mean daily vertical gradient of refractivity of each season. From figure 3, it is clear that the point of refractivity gradient dN_1 of winter is highest value followed by the point of refractivity gradient of autumn and the point of refractivity gradient of summer. We note that the point refractivity gradient varies from season to season. The gradient values are lower in summer season, than in winter season. This can be attributed to the decreasing humidity, the pressure; the increasing temperature in summer and the increasing of the water vapour pressure and the decreasing the temperature in winter.

4.4 dN_1 comparison with ITU maps

For each year, the mean monthly vertical gradient of refractivity calculated on the basis of the daily vertical gradient of refractivity for all day over the whole period of study (2009-2013). To determine the annual value of dN_1, the mean of each day of the given year are used. Table 2 shows the average annual value of the point of refractivity gradient dN_1.
For each year, we can note the following remarks:

- The main observation is that, whatever year, the obtained value of the point of refractivity gradient, dN_1 is different from the theoretical value of dN_1
- The obtained value of the point of refractivity gradient, dN_1 varies from the year 1 to the year 2. Again this gap is caused by the change of the metrological parameters in the lower troposphere from season to season and year to year.

5. Conclusion

The obtained values of the radio refractive index in this paper show that this index is a function of meteorological data, particularly the temperature, atmospheric pressure and water vapour pressure. Thus the estimation of the radio refractive index has to be based on local geographical and meteorological data, as confirmed by others researchers. The analysis of the obtained values of the vertical gradient of the radio refractivity shows that the value of this gradient also depends on local geographical and meteorological data. For example the obtained value of the gradient of the radio refractivity in this paper is lower than the value recommended by ITU-R for standard atmosphere.

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