Statistics of Radio Refractivity Derived from Prague Radiosounding Data

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Abstract. Vertical gradient of radio refractivity in the lowest 100 m is derived from the meteorological radiosounding data of the Prague-Libus station. The data cover the measurements at the times 00, 06, 12, and 18 UTC, and the extent of data is 20 years. Diurnal, monthly, and annual distributions are presented and the relative role of the dry and wet components of the refractivity gradient is discussed. The βν values, expressing the percentage of the time with the refractivity gradient below -100 km⁻¹, are presented. This work should enable the effective radio-relay link design with respect to the radiowave bending.

Keywords
Radio refractivity, meteorological radiosounding, probability of exceedance, diurnal variations, annual variations.

1. Introduction

Bending of the radio ray trajectory depends on the vertical distribution of radio refractive index N and is pronounced especially at longer ray path in the atmosphere. That is why the statistical properties of the vertical gradient of refractivity parameters can be useful information when the quality of radio-relay links and low-elevation satellite links is calculated. There are several studies of the statistical properties of radio refractivity. Much work in that field was done in the frame of COST 215 action [1], which finds the quality of radio-relay links and low-elevation satellite links is calculated. There are several studies of the statistical properties of radio refractivity. Much work in that field was done in the frame of COST 215 action [1], which finds a continuation in the running action COST 280, e.g. [2].

Based on the known refractive index n, the radio refractivity, N, is defined by:

\[ N = 10^n (n-1) . \] (1)

In terms of meteorological quantities, the N can be expressed as [1, 3, 4]:

\[ N = 77.6 \frac{p}{T} + 3.73 \times 10^5 \frac{e}{T^2} = N_d + N_w , \] (2)

where p (hPa) is the air pressure, T (K) is the temperature, e (hPa) is water vapor pressure, and \( N_d (N_w) \) is so called dry (wet) component of N. The e can be calculated from the relative humidity and from the saturation water pressure \( e_s \), the last depending only on the air temperature, T. In this paper we apply the relationship \( e_s(T) \) from the ITU-R recommendation [4] published also in [3]. From (2) it is clear that to evaluate the long-term statistics of the reflectivity profiles we can rely on the long-term meteorological radiosounding measurements, which provide vertical profiles of air pressure, temperature, humidity, wind speed and wind direction. We can determine the vertical gradient of N, \( dN/dz \), and consequently the \( dn/dz \) from the vertical profiles. The value of \( dN/dz = \approx 40 \text{ km}^{-1} \) corresponds to the standard atmosphere.

The last parameter, important in the studies of clear air propagation and interference, is the so-called \( \beta_e \) parameter. It is defined as the percentage of time, for which the radio refractivity gradient \( dN/dz \) is below \(-100 \text{ km}^{-1} \) in the lowest 100 meters above the ground, and it represents the probability that super-refracting “surface” layers occur at a given location (e.g. [1]).

In this study, we discuss the statistical characteristics of the gradient \( dN/dz \) in the lowest 100 m. We used the radiosounding data from the aerological station Prague Libus, operated by the Czech Hydrometeorological Institute (CHMI). The elevation of the station is 304 m a.s.l. and consequently, the \( dn/dz \) \( (\text{km}^{-1}) \) was calculated by:

\[ dN/dz = 10[N(404) - N(304)] , \] (3)

where \( N(z) \) is radio refractivity in the height z (m a.s.l.). The \( N(404) \) values were determined by linear interpolation from the nearest radiosounding levels below and above the 404 m a.s.l. In accordance with (2) and (3), we also determined the dry component and wet component of the refractivity gradient, \( dN_d/dz \) and \( dN_w/dz \), respectively.

This article is structured as follows. In Section 2, we introduce the input data and we show the basic statistical characteristics of N and \( dN/dz \). The distribution of \( dN/dz \) is presented in Section 3 and the particular role of the wet and dry component is discussed in Section 4. Section 5 is devoted to the basic statistical properties of \( \beta_e \) and \( k \). Section 6 shows the practical use of the described phenomena and Section 7 summarizes the results and the outlook for the further work.
2. Input Data and Basic Processing

The results of radiosounding measurements from the aerological station Prague-Libus (304 m a.s.l.) were used as the input data set for this study. Meteorological sonds are launched four times a day, at 00, 06, 12, and 18UTC, and the resulting data cover vertical profiles of air pressure, temperature, dew point temperature, wind speed and wind direction. From the dew point values we calculated the temperature, dew point temperature, wind speed and wind direction. We used the data from 20 years (1980 – 1991, 1994 -2001) and corresponding values of standard deviation are in parenthesis. The dry component of the refractivity gradient are shown in Fig. 1 for all terms considered. The dry component of the refractivity gradient and corresponding values of temperature gradient are also indicated. Fig. 1 shows the inverse proportion between the temperature gradient, \(\frac{dN}{dz}\), and the \(\frac{dN}{dz}\) while the course of \(\frac{dN}{dz}\) differs due to the effect of the \(\frac{dN}{dz}\). The daily change in the humidity disturbs the nearly regular daily course of temperature.

### Tab. 1.

<table>
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<tr>
<th>month / time</th>
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<th>06 UTC</th>
<th>12 UTC</th>
<th>18 UTC</th>
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<tr>
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<tr>
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<td>490</td>
<td>441</td>
<td>1911</td>
</tr>
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<td>508</td>
<td>517</td>
<td>483</td>
<td>462</td>
<td>1970</td>
</tr>
<tr>
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<td>515</td>
<td>497</td>
<td>458</td>
<td>434</td>
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<td>434</td>
<td>405</td>
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<td>453</td>
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<td>5772</td>
<td>5690</td>
<td>5319</td>
<td>22746</td>
</tr>
</tbody>
</table>

Tab. 1. The number of radiosoundings in the input data set

### Tab. 2.

<table>
<thead>
<tr>
<th>month</th>
<th>(N)</th>
<th>(\frac{dN}{dz})</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>304.9 (4.3)</td>
<td>-35.9 (11.2)</td>
</tr>
<tr>
<td>II</td>
<td>304.1 (5.2)</td>
<td>-37.6 (14.8)</td>
</tr>
<tr>
<td>III</td>
<td>304.4 (6.2)</td>
<td>-38.2 (19.7)</td>
</tr>
<tr>
<td>IV</td>
<td>304.8 (8.1)</td>
<td>-41.5 (26.5)</td>
</tr>
<tr>
<td>V</td>
<td>312.9 (11.0)</td>
<td>-49.0 (38.6)</td>
</tr>
<tr>
<td>VI</td>
<td>320.2 (12.1)</td>
<td>-51.2 (43.4)</td>
</tr>
<tr>
<td>VII</td>
<td>325.6 (11.9)</td>
<td>-54.1 (46.7)</td>
</tr>
<tr>
<td>VIII</td>
<td>325.8 (11.6)</td>
<td>-54.8 (48.6)</td>
</tr>
<tr>
<td>IX</td>
<td>321.3 (9.1)</td>
<td>-47.0 (38.4)</td>
</tr>
<tr>
<td>X</td>
<td>314.6 (8.5)</td>
<td>-40.1 (28.1)</td>
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<td>308.0 (5.4)</td>
<td>-37.7 (16.3)</td>
</tr>
<tr>
<td>XII</td>
<td>305.7 (4.8)</td>
<td>-36.7 (12.4)</td>
</tr>
<tr>
<td>year</td>
<td>312.4 (11.8)</td>
<td>-43.4 (31.9)</td>
</tr>
</tbody>
</table>

Tab. 2. Mean ground radio refractivity, \(N\), and mean radio refractivity gradient, \(\frac{dN}{dz}\), for all months and the year. Corresponding values of standard deviation are in parenthesis.

The \(N\) values were calculated according to (2) and the gradient values, \(\frac{dN}{dz}\), in the lowest 100 m according to (3). Tab. 2 gives the monthly and annual mean values of \(N(304)\) and \(\frac{dN}{dz}\) together with corresponding standard deviations. The negative mean \(\frac{dN}{dz}\) values confirm the decrease of \(N\) with the height in average. The mean values of the refractivity gradient are shown in Fig. 1 for all terms considered.

3. Distribution of \(\frac{dN}{dz}\)

In contrast to Fig. 1 showing the time dependence of the mean \(\frac{dN}{dz}\), Fig. 2 presents the quantile values corresponding to the \(\frac{dN}{dz}\) distribution. The extent of input data set allowed us to determine the individual distributions of \(\frac{dN}{dz}\) for each term and month during the year together with the overall monthly and annual distributions. Fig. 2 shows the annual course of \(\frac{dN}{dz}\) values given probability of exceedance. The large dispersion of the \(\frac{dN}{dz}\) distribution is obvious especially in summer. In Fig. 3 and Fig. 4, the curves depicting the probability of exceedance are shown to demonstrate the differences in monthly distributions (Fig. 3) and in the distributions relating to the time during the day (Fig. 4).
It is known that the wet part, $N_w$, represents a smaller portion of the $N$ value than the $N_d$ component. As an example, the mean monthly values $N_w/N$ and $N_d/N$ as well as the ratio $N_d/N_w$ are shown in Fig. 6.

Fig. 6. The $N_d$ and $N_w$ components relative to the $N$ value (left scale). The monthly and annual values are depicted by columns. The $N_d/N_w$ ratio (right scale) is marked by the empty squares and the annual value is labeled.

Fig. 7. The same as in Fig. 6 but for the gradient values.

Fig. 6 shows that the largest $N_w$ portion can be met in summer, however, its value does not exceed 20% of $N$. The same dependence of the gradient values (Fig. 7) shows a distinct picture with maximum relative $dN_w/dz$ of 47%. Therefore, the humidity gradient in the lowest 100 m is of high relevance to the $dN/dz$ values.

4. The Effect of Humidity on $dN/dz$

Fig. 1 indicates that the distribution of $dN/dz$ can be affected not only by the temperature gradient but also by the vertical change in the atmospheric humidity. This can be demonstrated in terms of the separate distributions for the dry and wet gradient component shown in Fig. 5.

5. Distribution of $\beta_0$ and $k$

The $\beta_0$ values were expressed by the relative frequency of the occurrence of $dN/dz<-100$ km$^{-1}$. The resulting $\beta_0$ values (for 00, 06, 12, 18UTC) are given in Fig. 8, which also indicates the monthly and annual values. The graph shows that the maximum $\beta_0$ can be met in summer months with maximum value 0.17 in July at 00UTC.

The earth refractivity coefficient, $k$, is defined as the ratio of the effective earth radius $R_e$ and the actual earth radius, $R$. It can be expressed by the relation:

$$k = \frac{R_e}{R} = \left(1 + R \frac{dN}{dz} \times 10^{-6} \right)^{-1}, \tag{4}$$
where \( dN/dz \) is the vertical gradient of the radio refractive index, \( N \). The annual distribution of the coefficient of earth refractivity \( k \) is shown in Fig. 9.

6. Use of \( k \) in Radio-Relay Calculation

Usually, the tropospheric refractivity index is not homogenous. That is why the radiowave trajectory, following the Fermat principle, is not linear. We can respect this fact by replacing the actual earth radius \( R \) by the effective radius, \( R_e \), using the earth refractivity \( k \) given by (4). In such case we can approximately consider the refractivity index to be homogenous, and consequently, the radiowave trajectory to be linear. As \( k > 1 \) for more than 96% of the time (see Fig. 9), the radiowave bending enables the trans-horizon propagation for more than 96% of the radiocommunications operation.

The correction respecting the bending of radiowave can be expressed by the term

\[
\Delta = \frac{d^2}{2kR},
\]

where \( \Delta \) represents the distance between the radiowave path (the tangent to the earth surface at the receiver position) and the earth surface at the distance \( d \) from the receiver (transmitter position). This correction respects the radiowave bending due to the variable \( k \).

7. Conclusion

This study summarizes the first results of the processing the radiosounding data from Prague-Libus station to determine the radio refractivity vertical gradient \( dN/dz \) in the lowest 100 m. The distributions of \( dN/dz \) and of its components are discussed and the effect on the radio-relay links is shown. The results show that the maximum negative \( dN/dz \) values can be expected in summer months when the humidity can achieve the highest values. This last result also corresponds to the annual distribution of \( \beta_0 \). Again the highest \( \beta_0 \) frequency occurs in summer. The derived \( k \) distribution can be used in the calculation of both radio-relay and satellite links.

The results, presented in this study, deal with the first part of the discussion of \( dN/dz \). At present, meteorological and practical aspects of \( dN/dz \) distribution are examined, which comprise e.g. the influence of temperature inversions and the dependence of \( dN/dz \) distribution on the large-scale meteorological pattern.

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References


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