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Variation of Radio Refractivity with Height above Ground

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Introduction

The structure of the radio refractive index, *n*, at the lower part of the atmosphere is a very important parameter in planning of the communication links. It is defined as a ratio of the radio wave propagation velocity in free space to its velocity in a specified medium [1–17]. Radio–wave propagation is determined by changes in the refractive index of air in the troposphere [2]. Changes in the value of the troposphere radio refractive index can curve the path of the propagating radio wave.

At standard atmosphere conditions near the Earth surface, the radio refractive index is equal to approximately 1.0003 [1]. As the conditions of propagation in the atmosphere vary from the standard ones, the anomalous radio-wave propagation is observed. Such anomalies are incident with some meteorological conditions (inversion of temperature, high evaporation and humidity, passing of the cold air over the warm surface and conversely) [3].

The atmosphere radio refractive index depends on air temperature, humidity, atmospheric pressure and water vapour pressure. Furthermore, air temperature, pressure and humidity depend on the height at a point above the ground surface. Even small changes in any of these variables can make a significant influence on radio-wave propagation, because radio signals can be refracted over whole signal path [4]. In a well–mixed atmosphere, pressure, temperature and humidity decrease exponentially as a function of height *h* [5].

The value of radio refractive index is very close to the unit and the changes in this value are very small in time and space. With the aim of making them more visible, the term of refractivity, *N*, is used [1, 3, 4, 6, 8].

Another important characteristic of the atmosphere is the vertical gradient of the refractive index, *G*. Profiles of *G* values in the 1 km interval above ground are important for the estimation of super–refraction and ducting phenomena and their effects on radar observations and VHF field strength at points beyond the horizon [9]. The vertical gradient of the refractive index is responsible for bending of propagation direction of the electromagnetic wave [12]. If it is negative, the signal bends downward.

It was mentioned in [9], that standard or normal propagation conditions of the radar beam (i.e. vertical refractivity gradients around -40 km^{-1} for the first kilometer above sea level) are considered to be the most representative. In [11], the question “How “normal” is normal propagation in Barcelona?” has been solved**.** The vertical profiles of the refractive index were analyzed in [2, 12].

Having in mind the variable climate of Baltic Sea Region, the influence of multipath conditions on line-of-sight radio link availability parameters is presented in [13]. Some fading-related problems of shortwave propagation for long distances in Baltic Region are analyzed in [14]. Variations of the radio refractive index at the ground surface have been analyzed in the localities of Latvia in [10]. The variable character of Lithuanian climate conditions is pointed up in [15, 16], where the rain influence on the radio signal propagation is analyzed. Seeing that the Lithuanian climate is very variable, variations of the radio refractive index at the ground surface have been analyzed in the localities of Lithuania in [3] and [17]. The seasonal and diurnal variations of radio refractivity near Earth's surface have been analyzed in the localities of Lithuania in the years 2008-2009.

The main goals of this paper were to analyze the dependences of average value of the radio refractivity N in different time of day in Vilnius on the seasons of the year in the years 2005-2010, and to determine the vertical radio refractivity gradient over Vilnius.

Estimation of the radio refractivity value

n-value is very close to the unit. The changes in n-value are very small in time and space. Therefore, term of refractivity, N, is used [1], [3–4], [6–8]:

$$N = (n-1)\times 10^6 . \quad (1)$$

According to [6]

$$N = A(p_0 + B\cdot p/T)/T , \quad (2)$$

where p_0 is the atmospheric pressure, p (hPa) is a partial water vapour pressure, T (K) is the absolute temperature, A=77.6K/hPa, B=4810 K.

This relationship is valid for all the radio frequencies up to 100 GHz; the error is less than 0.5% [6].

The radio refractivity gradient G (km^{-1}) is expressed as

$$G = \frac{N_1 - N_2}{h_1 - h_2} , \quad (3)$$

where N_1 and N_2 are radio refractivity values at heights h_1 and h_2 respectively.

The results and discussion

We used the data of daily meteorological observations performed at fixed time in Vilnius. The meteorological data and Vilnius Airport have been used in data manipuliation.

Table 1. The average daily temperature T (from 6 AM to 6 PM), relative humidity H, radio refractivity N, radio refractivity gradient G_1 at h_1=50 m, the radio refractivity gradient G_2 at h_2=600m, in November 2010

Day	T, K	H, %	N	G_1, km^{-1}	G_2, km^{-1}
2	281.3	81	317	-20.6	-5.0
4	279.9	89	317	-24.7	-4.3
6	278.0	93	315	-19.5	-5.1
8	275.0	97	312	-27.4	-9.0
10	280.1	95	316	-23.8	-7.1
12	277.0	92	311	-18.4	-5.3
14	261.7	86	318	-20.1	-5.2
16	278.7	93	321	-19.8	-8.1
18	281.4	95	323	-23.2	-7.4
20	277.6	99	322	-31.8	-4.6
22	276.6	94	318	-19.7	-5.7
24	276.0	93	308	-22.6	-4.8
26	272.1	94	307	- 9.1	-3.2
28	264.8	82	306	- 4.7	+1.5
30	261.2	72	304	-4.9	+2.6

The radio refractivity N has been determined using Eq. (2). The radio refractivity gradient G has been determined in accordance with Eq. (3).

The average daily temperature T in different time of day, relative humidity H, radio refractivity N, radio refractivity gradient G_1 at h_1=50 m, the radio refractivity gradient G_2 at h_2=600m, in November 2010, are presented in Table 1.

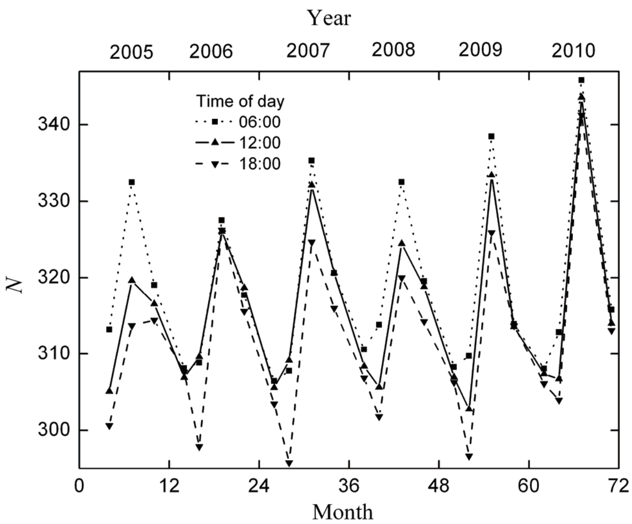

Fig. 1. Dependences of average value of the radio refractivity at the ground surface in different time of day in Vilnius on the seasons of the year in the years 2005–2010

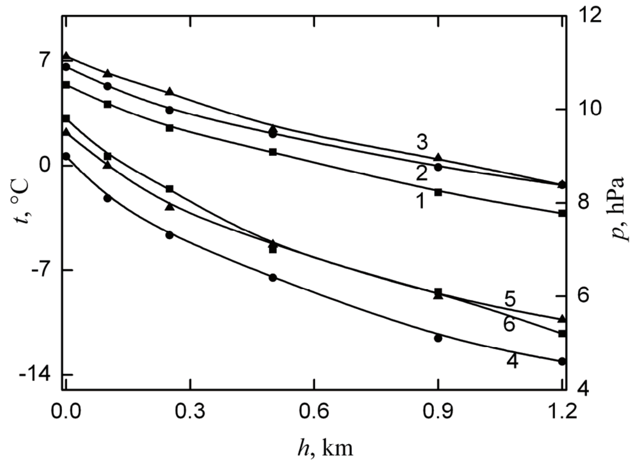

Fig. 2. The dependences of the average values of the air temperature t (curves 1-3), and the partial water vapour pressure (curves 4-6) on the height above the Earth surface in 11-20 November 2010, in Vilnius. Curves 1 and 4 correspond to 6 AM, curves 2 and 5 – to 12 AM, and curves 3 and 6 – to 6 PM

In Fig. 1, the dependency of N-value on months, corresponding to seasons, in Vilnius in the year 2005-2010, is presented. Months are marked as follows: months 1-12 correspond to year 2005, 13-24 – to 2006, and so on. In Fig. 1 can be seen, that behaviour of those dependencies repeats periodically (they are maximum in warm months and are minimum in cold months). In summer of the year 2010 it was raining significantly more than in previous years. Therefore, N-value was notably larger.

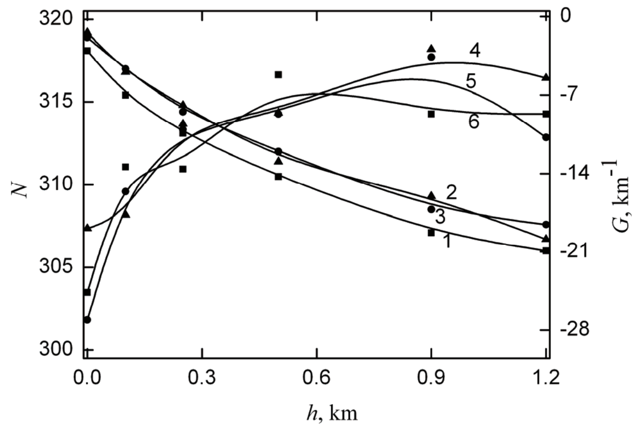

Fig. 3. The dependences of average *N*–values (curves 1-3) and its vertical gradient *G* (curves 4-6) on the height above the Earth surface on 11-20 November 2010, in Vilnius (second decade). Curves 1 and 4 correspond to 6 AM, curves 2 and 5 – to 12 AM, and curves 3 and 6 – to 6 PM

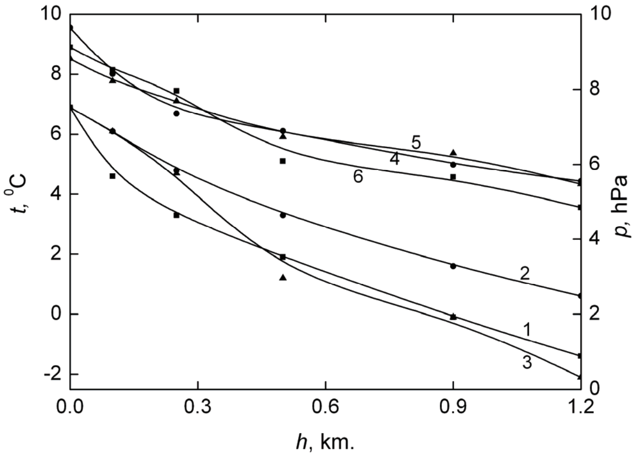

Fig. 4. The dependences of the air temperature *t* (curves 1-3) and the partial water vapour pressure (curves 4-6) on the height above the Earth surface on 4 November 2010, in Vilnius. Curves 1 and 4 correspond to 6 AM, curves 2 and 5 – to 12 AM, and curves 3 and 6 – to 6 PM

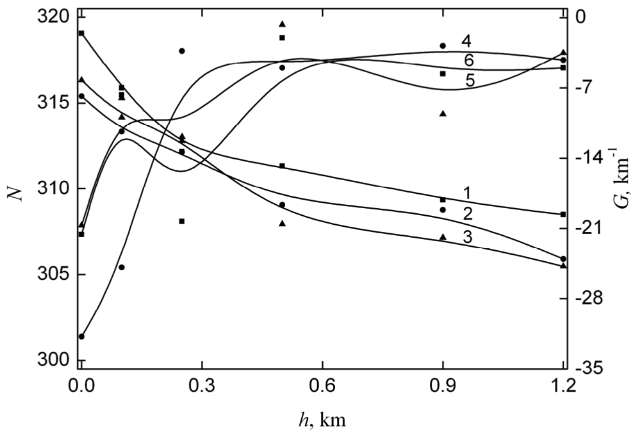

Fig. 5. The dependences of average *N*–values (curves 1-3) and its gradient *G* (curves 4-6) on the height above the Earth surface on 4 November 2010, in Vilnius. Curves 1 and 4 correspond to 6 AM, curves 2 and 5 – to 12 AM, and curves 3 and 6 – to 6 PM

Month number 71 corresponds to November 2010, which was selected for detail investigation because of variation of temperature in wide range (from positive temperature down to negative one), and was high humidity. The weather was no especially wet at the beginning of that month and the temperature was above 0°C. There was warm and humid weather at the middle of that month. The weather became cold sharply and the *N* decreased significantly at the end of November 2010. The *G* remained negative at the Earth surface only and it became positive in the higher layers.

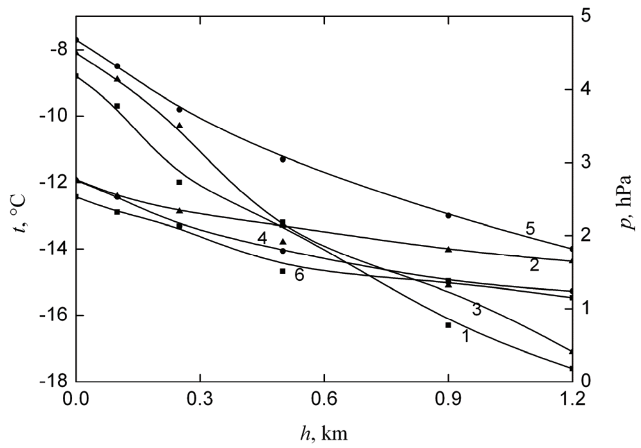

Fig. 6. The dependences of the air temperature *t* (curves 1-3) and the partial water vapour pressure (curves 4-6) on the height above the Earth's surface on 28 November 2010, in Vilnius. Curves 1 and 4 correspond 6 AM, curves 2 and 5 – to 12 AM, and curves 3 and 6 – to 6 PM

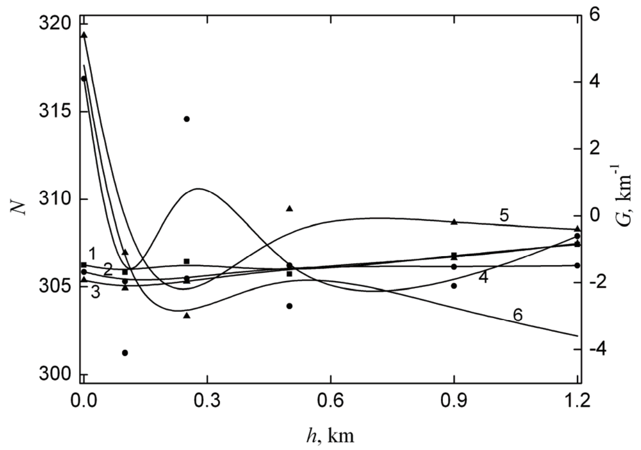

Fig. 7. The dependences of average *N*–values (curves 1-3) and its gradient *G* (curves 4-6) on the height above the Earth surface on 28 November 2010, in Vilnius (second decade). Curves 1 and 4 correspond to 6 AM, curves 2 and 5 – to 12 AM, and curves 3 and 6 – to 6 PM

The results are shown in Table 1 and Fig. 2-7. In summer 2010, the values of radio refractivity were significantly higher than usual values, because the air temperature was higher and air was more humid.

Conclusions

The vertical gradient of the radio refractivity was lower than the value, which was recommended by ITU-R (for standard atmosphere). When weather suddenly went cold, the inverse of the vertical gradient emerged. According to our research, in Lithuania the variations of the radio refractivity in seasons of the year are influenced by the changes in air humidity and temperature in the most part (the second term in Eq. (2)). The air pressure fell marginally at the heights analyzed here (it decreased about 4 hPa when the height increased up to 1.2 km) and there is slight influence of the first term in Eq. (2). The radio refractivity and its vertical gradient could change when the weather suddenly becomes significantly colder.

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In Vilnius, the daily and the seasonal variations of the radio refractivity values have been computed at the Earth surface in the years 2005–2010 and at the heights up to 1.2 km in November 2010. The International Telecommunications Union – Radiocommunications Sector (ITU–R) model was used for calculation of the radio refractive index according to the peculiarities of climatic conditions of Lithuania. As a result of obtained data analysis, the days with more variable meteorological parameters have been chosen for more detailed investigation. The radio refractivity gradient has been computed at the heights starting from the Earth surface up to 1.2 km above the ground, using the meteorological data measured at those heights. The variation of radio refractivity and its gradient are influenced by the changes in air’s humidity and temperature in most part. Ill. 7, bibl. 17, tabl. 1 (in English; abstracts in English and Lithuanian).

E. Valma, M. Tamošiūnaitė, S. Tamošiūnas, M. Tamošiūnienė, M. Žilinskas. Atmosferos lūžio rodiklio kitimas didėjant aukščiui // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2011. – Nr. 5(111). – P. 23–26.

Ištirtos oro lūžio rodiklio prie Žemės paviršiaus priklausomybės nuo paros ir metų laiko 2005–2010 metais Vilniuje bei jo priklausomybės nuo aukščio (iki 1,2 km) 2010 metų lapkričio mėnesį, kai meteorologinės sąlygos per mėnesį kito labiausiai. Oro lūžio rodiklis apskaičiuotas Tarptautinės telekomunikacijų sąjungos radiokomunikacijų sektoriaus (ITU–R) rekomenduojamu metodu. Parodyta, kad oro lūžio rodiklio ir jo gradiento pokyčius lemia ne oro slėgio, bet jo temperatūros ir drėgmės pokyčiai. Il. 7, bibl. 17, lent. 1 (anglų kalba; santraukos anglų ir lietuvių k.).