Lithuanian Journal of Physics, Vol. **48**, No. 1, pp. 65–72 (2008) doi:10.3952/lithjphys.48110

INFLUENCE OF CLOUDS ON ATTENUATION OF ELECTROMAGNETIC WAVES [*]

M. Tamošiūnaitė [a,b] S. Tamošiūnas [a,b] M. Tamošiūnienė [c], and M. Žilinskas [a,d]

[a] *Faculty of Physics, Vilnius University, Saulėtekio 9, LT-10222 Vilnius, Lithuania*
E-mail: stasys.tamosiunas@ff.vu.lt
[b] *Institute of Materials Science and Applied Research, Vilnius University, Saulėtekio 9, LT-10222 Vilnius, Lithuania*
[c] *Semiconductor Physics Institute, A. Goštauto 11, LT-01108 Vilnius, Lithuania*
[d] *Department of Radio Communication, Communications Regulatory Authority of the Republic of Lithuania, Algirdo 27, LT-03219 Vilnius, Lithuania*

Received 15 June 2007; revised 29 December 2007; accepted 22 February 2008

The semi-empirical method for determination of the cloud attenuation was used. The cloud attenuation was determined by using the meteorological data measured at the ground level. It was assumed that the clouds would form at some height above the ground level when the conditions for vapour condensation would be present and the liquid water content in the air would be above zero at that height. The values of height have been determined by using the values of temperature at the ground level, the dew point temperature, and the temperature gradient. The calculation results show that known relation between the temperature and the cloud base height is not always suitable for Lithuanian climate conditions. According to the meteorological data measured in the weather stations, relation between the height and temperature within the cloud, recommended by International Telecommunication Union, was chosen. Only summer profile was suitable to use under conditions investigated here. The values of relative humidity and temperature at the ground level were used in calculations of liquid water content within the clouds. The values of specific attenuation under conditions of cloud cover were computed by using the obtained liquid water content values at frequencies starting from 10 GHz and up to 70 GHz.

Keywords: electromagnetic waves, cloud attenuation, semi-empirical method

PACS: 41.20.Jb, 84.40.-x

1. Introduction

Raindrops and cloud particles can attenuate the electromagnetic waves propagating in atmosphere, especially at frequencies of 10 GHz and higher. The impairments, such as rain attenuation and cloud attenuation, become increasingly important with increasing operating frequency [1]. It is important to predict the possible attenuation due to rain and clouds when new communication systems are projected. The rain attenuation has been widely analysed in past decades in various regions. The effect of rain on radio wave propagation is greater than that of clouds in many cases but the occurrence of clouds is always more often than rains [2]. However, the attenuation due to clouds has not been analysed enough.

The particles of water or ice, of which consist the clouds, are very small. The diameter of these particles is 0.01 cm or less [3]. The sizes of cloud drops vary from one cloud type to another. There are several types of clouds such as Cirrus (Ci), Cirrocumulus (Cc), Cirrostratus (Cs), Cumulus (Cu), Altocumulus (Ac), Stratocumulus (Sc), Altostratus (Ac), Cumulonimbus (Cb), Nimbostratus (Ns), Stratus (St), etc. Three classes of clouds are distinguished according to their usual altitudes: high (the cloud base heights of 6–13 km), middle (the cloud base heights of 2–7 km), and low (the cloud base heights of 2 km and less).

The liquid water content M is one of the most important parameters of the clouds. M describes the mass of water drops in the volume units. It has been mentioned in [4] that the specific cloud attenuation α (dB/km) is a function of the liquid water content M (g/m^3), the frequency f, and the temperature within the cloud T. Measurements of the liquid water content M at a point in space or averaged over a radio wave path are complicated [5]. Direct methods for measuring M consists of extracting a known volume through a cotton pad or

---

[*] The report presented at the 37th Lithuanian National Physics Conference, 11–13 June 2007, Vilnius, Lithuania.

ISSN 1648-8504

of rotating cups in an impeller apparatus, both to be weighed; also, resistance changes can be measured with a hot wire probe attached to an aircraft flying through clouds [5]. The liquid water content in the cloud varies in a wide range. The large Cumulonimbus and Cumulus Congestus that accompany thunderstorms have especially high values of liquid water content; fair weather Cumulus clouds generally have liquid water content of less than 1 $\mathrm{g/m^3}$ [4]. Stratiform or layered clouds display ranges of 0.05–0.25 $\mathrm{g/m^3}$ [6]. Stratocumulus is the densest of this cloud type (0.3–1.3 $\mathrm{g/m^3}$) [4]. Sometimes, the values of M exceed 5 $\mathrm{g/m^3}$ in Cumulus Congestus; an average value of 2 $\mathrm{g/m^3}$ for Cumulus Congestus and 2.5 $\mathrm{g/m^3}$ for Cumulonimbus clouds are reported in [4] and [6]. In most of the cloud attenuation models, the knowledge of liquid water content is required. The climate conditions (humidity, temperature, rain rate, etc.) and cloud morphology are different over various localities of several regions; accordingly, the liquid water contents differ within the clouds as well. This factor must be considered when analysing rain attenuation and cloud attenuation. The cloud attenuation in various regions was analysed in [1, 2, 7–12].

The attenuation of radio waves due to rain under Lithuanian climatic conditions was analysed in [13–16]. However, the influence of clouds on the electromagnetic wave propagation under the Lithuanian climatic conditions, as far as we know, has not been analysed.

The humid weather predominates over the year in Lithuania. The precipitation amount is probably the most changeable meteorological index on its territory. It varies from 901 mm in Šilalė District to 520 mm in Pakruojis District [17]. On average, the clouds cover more than 50% of the territory of the country. In Lithuania, according the data of its weather stations, November and December are the cloudiest months. The clearest sky is in May and June in Lithuania. Vilnius and Kaunas are the cloudiest localities. Nida is the most cloudless locality. There are about 100 overcast days in the year in the country. The peculiarities of Lithuanian climate are the reason to specify the suitability of the cloud attenuation models developed in the other regions for use under the climate conditions mentioned above. The main goal of this paper was to determine the specific cloud attenuation under the Lithuanian climatic conditions.

2. Calculation of the specific cloud attenuation

There were developed several cloud attenuation models. In [4], the specific cloud attenuation α (dB/km) was expressed as the function of liquid water content M,

$$\alpha = K_\mathrm{c} M\,, \qquad (1)$$

where K_c is the attenuation constant.

The attenuation constant K_c is the function of frequency f and temperature T. The values of K_c for pure water droplets are presented in [4]. In [4], it was mentioned that the values of K_c for salt–water droplets (over the sea and ocean surfaces) are higher. The necessity to know M value is limiting the direct use of relationship (1).

Using approximation for the specific cloud attenuation in [1, 2, 7–9], the specific cloud attenuation was expressed as

$$\alpha = \frac{4.343 \cdot 10^{0.0122(291-T)-1} \cdot 1.16\,M}{\lambda^2}\,, \qquad (2)$$

where T is the absolute temperature (K) at the height h (km) where the clouds would be formed, λ is the wavelength (cm), and M is the liquid water content ($\mathrm{g/m^3}$).

The model (2) is useful from about 10 to 50 GHz. The knowledge of the liquid water content M is the main problem when using relation (2) and the uncertainty of M limits the accuracy to which the specific cloud attenuation can be computed by using relation (2).

As mentioned above, the direct measurement of liquid water content M is complicated, and a model for determining this parameter is required. The expression of liquid water content was presented in [8]; semi-empirical model (2) for cloud attenuation was used. The annual cumulative statistics of cloud attenuation were predicted from ground-based relative humidity and temperature measurements. Some of the model parameters carried out at 20 and 30 GHz frequencies.

In [9], the average value of the liquid water content $M = 0.57$ $\mathrm{g/m^3}$ was taken. It was assumed that the cloud temperature during winter months was around 260 K, and the cloud particle temperature during summer months was about 276 K. It was concluded in [9] that at temperatures mentioned above and at frequency of 20 GHz the range of specific attenuation due to clouds was from 0.0486 to 0.0762 dB/km; and it was obtained to be from 4.8627 to 7.6222 dB/km at frequency of 100 GHz.

Calculation method of cloud attenuation using vertical profiles of temperature and humidity as input parameters was presented in [10]. Two types of data were available: meteorological quantities (pressure, humidity, temperature, total cloudiness, etc.) measured at the ground level, and the vertical profiles of pressure, temperature, humidity, and wind measured with the radiosonde instruments. The data from six years of routine meteorological observations at stations in Europe were used in the propagation studies. The authors believe that the method can be applied to middle altitude climates for elevation angles from 15 to 40°. In [11], a cloud attenuation model based on available cloud cover data and the average properties of different cloud types was developed. In addition, different cloud types can be presented simultaneously at a variety of heights. The average properties of four cloud types used in [11] were: Cumulonimbus clouds ($M = 1.0\ \mathrm{g/m^3}$), Cumulus ($M = 0.6\ \mathrm{g/m^3}$), Nimbostratus ($M = 1.0\ \mathrm{g/m^3}$), Stratus ($M = 0.4\ \mathrm{g/m^3}$). It was assumed in [11] that dependence of cloud attenuation on temperature was a second order effect and the specific attenuation calculated at 0 °C was used in the model.

In [12], total atmospheric attenuation under conditions of cloud cover was measured at frequencies of 15 and 35 GHz in the Boston area. Attenuations were measured at both frequencies simultaneously and then correlated with the only meaningful meteorological parameter that could be readily determined, the surface absolute humidity. In [12], it was mentioned that cloud attenuation was primarily due to absorption by the cloud droplets; scattering losses were secondary. For clouds at an altitude above the zero degree isotherms, absorption by ice particle is negligible because the imaginary component of the index of refraction of ice is very small. A linear regression of zenith attenuation as a function of surface absolute humidity was performed in [12]. The frequency dependence of the cloud attenuation was studied. An algorithm estimating total atmospheric attenuation as a function of elevation angle, frequency, and surface absolute humidity was derived. The following expression for the zenith attenuation for complete cloud cover was presented in [12]:

$$A_\mathrm{z} = (-0.0242+0.00075\lambda+0.403\lambda^{-1.15})(11.3+\rho_0)\,, \tag{3}$$

where A_z is in dB, λ is the wavelength in millimetres, and ρ_0 is the surface absolute humidity in $\mathrm{g/m^3}$.

In [12], it has been mentioned that this is believed valid for the window regions from 15 to 100 GHz. It has been pointed up in [12] that the values of attenuation for cloud, mixed cloud, and clear sky conditions converge to approximately the same value for very low humidity. For higher humidity the mixed cloud attenuations are approximately 85% of the attenuations for full cloud cover at both 35 and 15 GHz.

We have determined the attenuation due to clouds under Lithuanian climatic conditions for the first time. The direct use of models mentioned above is limited in our case: the use of models of [1, 2, 7–9] requires the knowledge of the values of cloud temperature and water content; there has been no possibility to measure the vertical profiles of pressure, temperature, and humidity with the radiosondes, and the use of model [10] has been restricted; the model [11] can be used at frequencies between 4 and 35 GHz, although the best accuracy will be found between 10 and 30 GHz. The empirical equation (3) has been derived for a cloud temperature of 10 °C and is suitable to use under climate conditions similar to the Boston climate. Equation (3) is a model for complete cloud cover.

There was no possibility to measure the specific cloud attenuation as well as the liquid water content and temperature within the clouds. Seeing that, the method that required only the meteorological parameters measured at the ground level was chosen. We used the basic idea of the model [8]: the water vapour in the atmosphere would lead to the formation of clouds whenever there were a possibility for condensation at some height h above ground level. It is mentioned in [8] that the condensation is possible when the water vapour density ρ exceeds the saturation density ρ_s at temperature T prevailing at that height. It is assumed in [8] that the water vapour density ρ can be estimated from humidity measurements carried out at ground level.

The height at which cloud exists is very important for accurate determination of results on attenuation due to clouds [2]. It was assumed in [8] and [18] that clouds are created starting in the vicinity of the height h, and h (km) follows ground temperature T_0 (K) as

$$h = 0.89 + 0.165(T_0 - 273)\,. \tag{4}$$

Relation (4) is based on analyses of temperature profiles in rain and on the Aerological Data of Japan and we have specified the applicability of this relation in the territory of Lithuania.

The condensed water content M is estimated as the difference between ρ and saturation density ρ_s at cloud temperature [8]:

$$M = \rho - \rho_\mathrm{s}\,, \tag{5}$$

where ρ_s ($\mathrm{g/m^3}$) is the saturated vapour density.

It is assumed that clouds are formed when $M > 0$. As mentioned above, the determination of the water content value M is complicated. Its values differ in each group of the clouds (the clouds are grouped according to their shape, height, and structure). In our calculation, the main problem was to determine M.

According to [8], the values of water vapour density ρ at the height h can be estimated from the equation of state, assuming an adiabatic process:

$$\rho = \frac{\rho_0 T_0}{T}\left[1 - \frac{\kappa - 1}{\kappa}\,\frac{\mu g h}{R T_0}\right]^{\kappa/(\kappa-1)}, \qquad (6)$$

where ρ_0 is the water vapour density at the ground level, T_0 is the ground level temperature, T is the absolute temperature in the vicinity of h, κ denotes the specific heat ratio which is $4/3$ for the water vapour molecule, μ is the water molar mass, g is the acceleration due to gravity, h is the height, and R is the fundamental gas constant.

The values of ρ_0 can be determined by using known relations [4].

3. Analysis of cloud cover data and calculation results

We assume that the clouds are created starting in the vicinity of the height h. We determine the values of h by using relation (4) or the data of the dew point temperature, temperature at the ground level, and the temperature gradient of 6.5 °C/km [19]. The values of h obtained here we compare with the cloud base height values measured at the weather stations.

The analysis of the cloud cover over the localities of Lithuania data shows that the relationship (4) can be used only in the cases when the middle or high clouds are formed over those localities. Data of the cloud cover over Vilnius in April 2007 (`http://rp5.ru//aselect.php`) was analysed. According to data of weather station, the cloud base heights of 2.0–2.5 km prevailed (19 events) in April 2007; the cloud base heights of 1.5–2.0 km were in three cases; the cloud base height of 1.0–1.5 km was only in one case; the cloud base heights of 0.3–0.6 km were in two cases. In five cases, the cloud base heights were 0.6–1.0 km.

The temperature at the ground level and the values of the cloud base heights (data of weather stations) in Vilnius in April 2007 (some events), as well as the height h determined using relationship (4) are presented in Table 1. It is worth to mention that relation (4) is suitable in the cases mentioned above when $h = 2.0$–2.5 km and the temperature at the ground level $t \leq 10$ °C. When $h = 2.0$–2.5 km and $t > 10$ °C, the values of h determined using relation (4) are too high. The results confirm our suspicion that the relationship is not suitable when the low clouds occur over the location investigated here. The values of cloud base heights obtained using (4) are more than two times higher than the measured values of h when the low clouds occur.

Table 1. Temperature at the ground level and the values of the cloud base heights (data of weather station) in Vilnius in April 2007, as well as the height h determined using equation (4).

T_0 (K)	Cloud base height, km (data of weather station)	Cloud base height (equation (4))
280.1	0.6–1.0	2.06
280.1	2.0–2.5	2.06
280.4	2.0–2.5	2.11
281.5	2.0–2.5	2.29
281.6	2.0–2.5	2.31
282.6	2.0–2.5	2.47
284.4	2.0–2.5	2.77

However, as mentioned above, humid weather predominates in Lithuania and the low clouds are formed frequently over the localities in autumn and winter. According to the weather station data, in January 2007, the low clouds with the cloud base height of 0.3–0.6 km were formed over Vilnius in most cases (16 events); in 6 events, the cloud base height was 0.2–0.3 km; in one case, the humidity of 100% was at the ground level; the cloud base heights of 0.6–1.0 km were in three cases; the cloud base heights of 1.0–1.5 km were only in two cases, and $h = 2.0$–2.5 km were observed in three cases.

Analysis of the values of the base heights in December 2006 over Kaunas and of the number of days when the clouds occurred at that height showed that in most cases the cloud heights of 0.2–0.3 km (8 events) and those of 0.3–0.6 km (8 events) were observed. Stratocumulus clouds have been formed over Kaunas in 11 of 16 events mentioned above. In 5 events, Cumulus clouds have been formed at the height starting from 0.2 up to 0.6 km. In 3 events, Stratocumulus (Sc) clouds have been formed at the height of 0.1–0.2 km over Kaunas in that month. In Kaunas, even on 16 days, the cloud base heights of 0.2–0.6 km were in December 2006. It is evident that the relation (4) is not suitable in most cases mentioned above. In 7 events, low clouds have not been formed over Kaunas and the heights of the middle cloud bases were starting from 2 up to 2.5 km. On 18 days, Altocumulus clouds were over Kaunas on December 2006. The temperature at the ground level and the values of the cloud base heights (data of weather stations) in Kaunas in December 2006 (some events), as well as the height h determined using relationship (4) are presented in Table 2. There is a clear discrepancy

Table 2. Temperature at the ground level and the values of the cloud base heights (data of weather station) in Kaunas in December 2006, as well as the height h determined using equation (4).

T_0 (K)	Cloud base height, km (data of weather station)	Cloud base height (equation (4))
275.4	0.1–0.2	1.29
278.5	0.1–0.2	1.80
274.6	0.1–0.2	1.15
280.6	0.2–0.3	2.14
278.3	0.2–0.3	1.76
277.4	0.2–0.3	1.62
271.5	0.6–1.0	0.64

between the data of weather station and the values obtained using relationship (4) in most cases. Only in one case, when $T_0 = 271.5$ K, the h value of weather station and the value determined using relationship (4) are in good coincidence. It is evident that under Lithuanian climate conditions the height at which the clouds can be formed cannot be estimated by using only the value of temperature at the ground level in most cases. The data presented in Table 1 (two cases when the temperature T_0 was 280.1 K, but the cloud base heights differed by 2.5–3.3 times on both events) confirmed this conclusion.

It is known that the cloud base height is the point where the temperature and dew point are equivalent; the relative humidity is 100% at this point in the space. If a dew point and the temperature at the ground level are known, the value of h can be obtained by using a temperature gradient. As an average, in [19], International Standard Atmosphere with a temperature gradient of 6.5 °C/km from sea level up to 12 km was defined. Analysis of the cover data over Lithuania shows that the low clouds base height is near the height obtained from the difference between the temperature at the ground level and the dew point temperature divided by the gradient of temperature [19]. In most frequent events, the Stratocumulus clouds have been formed at the height of 0.3–0.6 km; the Cumulus clouds occur at the height of 1.0–1.5 km. In our approach, for low clouds, the temperature at the cloud height is the temperature at the height of the upper mark of the base height.

The values of temperature at the ground level were taken from the archives of the weather stations (`http://rp5.ru//aselect.php`). It was assumed in [8] that the cloud temperature $T \approx 270$ K. In our approach, the values of T were determined according to the ITU-R Recommendation [19]. A suitable to Lithuanian climatic conditions relation between T and h values was chosen when the latitude of the locality and the average daily temperature were considered. It is well known that the difference of temperature within the cloud and its surrounding air is hardly one tenth of a degree Celsius [1]. In the light of this fact, the temperature at height h is the temperature of the cloud in our study. Analysis of the calculation results and meteorological data shows that only summer temperature profile [19] can be useful in calculation of the temperature at the height h under conditions of the warm period of the year (see Table 3). The winter profile [19] is not always suitable to use under the winter conditions in Lithuania.

Table 3. Values of temperature at the ground level, T_0, and at the height h: T_1 obtained by using ITU-R summer profile [19] and T_2 obtained by using temperature gradient [19].

T_0, K	291.0
h, km	2.5
T_1, K	274.01
T_2, K	274.75

Using the value of relative humidity H_0, temperature T_0, and the value of saturation vapour density $\rho_{0\mathrm{s}}$, the water vapour density at the ground level ρ_0 has been determined. The equation of state, assuming an adiabatic process (6), has been used for determining of the water vapour density ρ at the height h.

The values of M presented in Table 4 were determined using values of ρ_0, T_0, T, and h. The types of the clouds are presented in Table 4 as well. When $M > 0$, the clouds may occur. The calculation results show that the average value of M is 0.51 g/m^3 (when averaging all the values presented in Table 4). Stratocumulus clouds were formed over localities investigated here most frequently. In our calculations, the average value of M for Stratocumulus clouds has been 0.5 g/m^3, and this value is from the range of values presented in [4] and near the value of $M = 0.57$ g/m^3 used in [9].

As mentioned above, the specific cloud attenuation α was expressed in [4] as the liquid water content M multiplied by the attenuation constant K_c, which is the function of frequency f and temperature T (see Eq. (1)). The values of K_c for temperatures $t = 0$ °C and 10 °C, and for frequencies f from 10 up to 70 GHz were taken from [4]. The dependences of specific cloud attenuation α on frequency f determined by using the relations (1) and (2) are presented in Figs. 1 and 2. There is a marked discrepancy between two values of specific cloud attenuation determined by using relations (1) and (2) when $f > 40$ GHz. It can be explained by the fact that the model (2) is useful from about 10 to about

Table 4. Values of the liquid water content M and the types of the clouds.

M, g/m^3	0.54	0.74	0.69	0.66	0.51	0.22	0.37	0.51	0.33
Cloud type	Sc	Sc	Ac	St	Sc	Ac	Sc	Sc	Sc

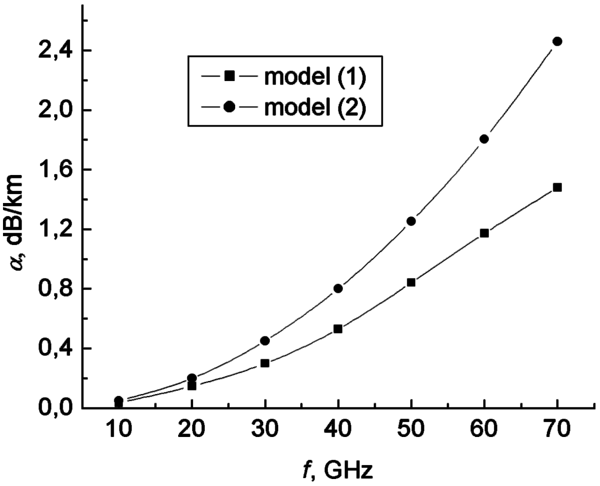

Fig. 1. Dependences of the cloud attenuation α on the frequency f determined by using relationships (1) and (2) when temperature $t = 10\,^\circ$C and the liquid water content $M = 0.5$ g/m^3.

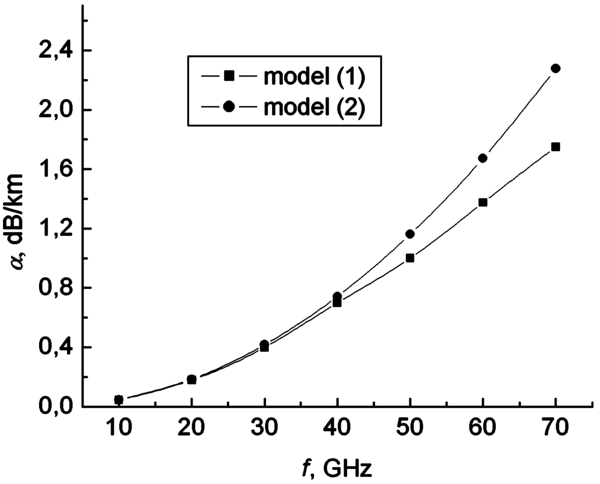

Fig. 2. Dependences of the cloud attenuation α on the frequency f determined by using relationships (1) and (2) when temperature $t = 0\,^\circ$C and the liquid water content $M = 0.5$ g/m^3.

50 GHz. The values of α presented in Figs. 1 and 2 confirmed the conclusion of [20] paper that all cloud attenuation models tend to agree at frequencies below 40 GHz, and above 40 GHz the models diverge from each other. The discrepancy between two values of specific cloud attenuation determined by using relations (1) and (2) becomes more noticeable when temperature increases (see Figs. 1 and 2).

It was mentioned in [2] that with increase in frequency the attenuation due to cloud also increases, but as the temperature of the cloud decreases the attenuation value increases. The results presented in Figs. 1 and 2 confirm that conclusion. At frequency of 20 GHz and cloud temperature $T = 273$ K, the value of the specific cloud attenuation α is 1.2 times higher than one at $T = 283$ K. The maximum values of α obtained here (when $f = 70$ GHz) show that it is important to predict the cloud attenuation when communication systems are planned in Lithuania.

The method described here is very practical. The values of M for determination of the specific cloud attenuation are easy to get by using the values of temperature and relative humidity measured at the ground level when the statistics of the cloud type and the base heights over localities are collected.

4. Conclusions

The attenuation due to clouds under Lithuanian climatic conditions has been determined for the first time. Considering that there was no possibility to measure the specific cloud attenuation as well as the liquid water content and temperature within the clouds, the method that requires only the meteorological parameters measured at the ground level was chosen. In calculations, the basic idea of the model [8] was used. As distinct from [8], the temperature of the cloud particle has been determined by using ITU-R relation [19], chosen when the climatic conditions and geographical location are considered, and using meteorological data of dew point; the height where the clouds are formed has been determined from the difference between the temperature at the ground level and the dew point temperature divided by the temperature gradient or by using the cloud base height data of weather stations. Only summer temperature profile [19] can be useful in calculation of the temperature at height h under the conditions of warm period of the year in the localities investigated here. The winter profile [19] is unsuitable for use under the winter conditions in Lithuania.

The calculation results show that model (4) can be used only for determination of the middle and high clouds base height under the Lithuanian climatic conditions if $t \leq 10\,^\circ$C. When $t > 10\,^\circ$C, the values of h determined by using relation (4) are too high. Commonly, the low clouds appear over the localities investigated here in the cold period of the year and sometimes in the warm period as well. Under Lithuanian climate conditions, the height at which the clouds can be formed cannot be estimated by using only the value of temperature at the ground level in most cases.

The low clouds base height may be determined by using the dew point temperature, the ground level temperature (if the mentioned parameters are available), and the temperature gradient [19].

The maximum value of $\alpha = 2.46$ dB/km (when $f = 70$ GHz) obtained here shows that it is important to predict the cloud attenuation when communication systems are planned in Lithuania.

References

[1] S.K. Sarkar, A. Kumar, I. Ahmad, and M.M. Gupta, Cloud morphology over three Indian tropical stations for Earth space communication, Int. J. Infrared Millimeter Waves **27**(7), 1005–1017 (2006).

[2] S.K. Sarkar, I. Ahmad, J. Das, and A.K. De, Cloud height, cloud temperature and cloud attenuation in microwave and millimeter wave frequency bands over Indian tropical east coast, Int. J. Infrared Millimeter Waves **26**(2), 329–340 (2005).

[3] A. Ishimaru, *Wave Propagation and Scattering in Random Media* (Academic Press, New York, San Francisco, London, 1978).

[4] R.L. Freeman, *Radio System Design for Telecommunications* (John Wiley & Sons, New York, Chichester, Weinheim, Brisbane, Singapore, Toronto, 1997).

[5] H.J. Liebe, T. Manabe, and G.A. Hufford, Millimeter-wave attenuation and delay rates due to fog / cloud conditions, IEEE Trans. Antennas Propag. **37**(12), 1617–1623 (1989).

[6] H.K. Weickmann and H.J. Kaumpe, Physical properties of cumulus clouds, J. Meteorol. **10**(3), 204–211 (1953).

[7] S.D. Slobin, Microwave noise temperature and attenuation of clouds: Statistics of these effects at various sites in the United States, Alaska, and Hawaii, Radio Sci. **17**(6), 1443–1454 (1982).

[8] F. Dintelmann and G. Ortgies, Semiempirical model for cloud attenuation prediction, Electron. Lett. **25**(22), 1487–1488 (1989).

[9] H. Chen, J. Dai, and Y. Liu, Effect of fog and clouds on the image quality in millimeter communications, Int. J. Infrared Millimeter Waves **25**(5), 749–757 (2004).

[10] E. Salonen and S. Uppala, New prediction method of cloud attenuation, Electron. Lett. **27**(12), 1106–1108 (1991).

[11] A. Dissanayake, J. Allnutt, and F. Haidara, A prediction model that combines rain attenuation and other propagation impairments along Earth-satellite paths, IEEE Trans. Antennas Propag. **45**(10), 1546–1558 (1997).

[12] E.E. Altshuler and R.A. Marr, Cloud attenuation at millimeter wavelengths, IEEE Trans. Antennas Propag. **37**(11), 1473–1479 (1989).

[13] S. Tamošiūnas, M. Žilinskas, A. Nekrošius, and M. Tamošiūnienė, Calculation of radio signal attenuation using local precipitation data, Lithuanian J. Phys. **45**(5), 353–357 (2005).

[14] S. Tamošiūnas, M. Žilinskas, M. Šileika, and M. Tamošiūnienė, Revised model of attenuation of electromagnetic waves due to rain, Lithuanian J. Phys. **46**(4), 433–436 (2006).

[15] S. Tamošiūnas, M. Tamošiūnienė, and M. Žilinskas, Calculation of electromagnetic wave attenuation due to rain using rainfall data of long and short duration, Lithuanian J. Phys. **47**(2), 163–168 (2007).

[16] M. Zilinskas, S. Tamosiunas, and M. Tamosiuniene, Calculation of radio signal attenuation using annual precipitation and heavy rainfall data, in: *18th International Wroclaw Symposium and Exhibition on Electromagnetic Compatibility*, Wroclaw, 28–30 June, 2006 (Wroclaw, Oficyna Wydawnicza Politechniki Wroclawskiej, 2006) pp. 490–493 .

[17] A. Bukantis, Climate fluctuations in Lithuania against a background of global warming, Acta Zool. Lituanica **11**(2), 113–120 (2001).

[18] S. Ito, Dependence of 0 °C isotherm height on temperature at ground level in rain, Trans. IEICE **E72**(2), 98–100 (1989).

[19] *Reference Standard Atmospheres. Draft Revision to Recommendation ITU-R P.835-3* (1992–1994–1997–1999–2004).

[20] G.C. Gerace and E.K. Smith, A comparison of cloud models, IEEE Antennas Propag. Mag. **32**(5), 32–38 (1990).

DEBESŲ ĮTAKA ELEKTROMAGNETINIŲ BANGŲ SILPNINIMUI

M. Tamošiūnaitė [a,b], S. Tamošiūnas [a,b], M. Tamošiūnienė [c], M. Žilinskas [a,d]

[a] *Vilniaus universiteto Fizikos fakultetas, Vilnius, Lietuva*
[b] *Vilniaus universiteto Medžiagotyros ir taikomųjų mokslų institutas, Vilnius, Lietuva*
[c] *Puslaidininkių fizikos institutas, Vilnius, Lietuva*
[d] *Lietuvos Respublikos Ryšių reguliavimo tarnyba, Vilnius, Lietuva*

Santrauka

Yra žinoma, kad vidutinis metinis debesuotumas Lietuvoje yra didesnis nei 50%. Debesys turi įtakos atmosfera sklindančių bangų sklidimui (jas silpnina). Savitasis silpninimas (dB/km) yra plačiose ribose kintančio debesies vandeningumo (g/m^3), signalo dažnio ir temperatūros funkcija. Savitasis elektromagnetinių bangų silpninimas debesyse nustatytas pusiau empiriniu metodu iš žemės paviršiuje išmatuotų meteorologinių duomenų – oro santykinės drėgmės ir temperatūros, laikant, kad iš vandens garų atmosferoje susiformuos debesys, jei nuo oro temperatūros ties žemės paviršiumi priklausančiame aukštyje bus sąlygos vandens garų kondensavimuisi, t. y. jei vandens garų tankis ρ viršys soties garų tankį tame aukštyje ρ_s. Aukštis, kuriame gali būti debesų, apskaičiuotas pagal žinomą jo ir temperatūros prie žemės paviršiaus sąryšį bei pasinaudojus meteorologinių stočių duomenimis. Skaičiavimo rezultatai parodė, kad minėtas sąryšis Lietuvos klimato sąlygomis tinka tik tada, kai nėra žemutinio aukšto debesų. Kai debesys susiformavo žemutiniame aukšte, jų žemutinės ribos aukštis nustatytas pasinaudojus meteorologijos stočių duomenimis. Temperatūros vertės tame aukštyje apskaičiuotos pagal Tarptautinės telekomunikacijų sąjungos (ITU-R) rekomenduojamą aukščio ir temperatūros sąryšį, atsižvelgus į vietovės geografinę platumą, vidutinę paros temperatūrą ir metų laiką arba į rasos taško temperatūrą. Rasta, kad tik vasaros mėnesiams rekomenduojamas aukščio ir temperatūros sąryšis gali būti naudojamas Lietuvos klimato sąlygomis. Kitais atvejais temperatūros vertė aukštyje h pasirinkta artima rasos taško temperatūrai arba pasinaudojus temperatūros prie žemės paviršiaus ir ITU-R rekomenduojama Standartinės atmosferos temperatūros gradiento verte. Savitasis silpninimas debesyse apskaičiuotas pasinaudojus žinomais sąryšiais. Kai $f < 40$ GHz, savitojo silpninimo vertės, apskaičiuotos skirtingais metodais, neblogai sutampa. Savitojo silpninimo debesyse vertės, gautos pasinaudojus čia aprašytais metodais, gali būti būdingos radijo ryšiui Lietuvoje didesnę metų laiko dalį. Gautos savitojo silpninimo debesyse vertės rodo, kad į jas reikia atsižvelgti ir numatyti priemones, kurios galimą silpninimą kompensuotų.