Application of Water Vapour Profiling for Gaseous Attenuation Estimation – Radiometer versus Radiosonde Results

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ABSTRACT

The statistics of estimated total gaseous attenuation are studied using vertical profiles obtained from both radiosonde and radiometer data measured during three months in summer 2008. The differences between gaseous attenuation statistics obtained from vertical profiles measured by radiosonde and from vertical profiles estimated from the radiometer measurements are analyzed. Statistic dependence on the frequency is revealed.

1. INTRODUCTION

Gaseous attenuation of electromagnetic waves can influence the remote-sensing or telecommunication radio systems operating on slant propagation paths through the troposphere. Absorption by molecular oxygen and absorption by water vapour form the most significant parts of total gaseous attenuation for frequencies 1 – 350 GHz [1]. Fluctuations of water vapour density profile in the troposphere cause the changes in attenuation and so determine the statistical characteristics of attenuation. The water vapour profiles as well as the profiles of other physical quantities of the air are retrieved from standard radiosonde measurements or they can be estimated from microwave radiometer measurements. In order to obtain the reliable estimates of gaseous attenuation, the errors inherent in radiometric profiling have to be assessed.

Specific gaseous attenuation along the vertical propagation path is calculated using the procedure defined by ITU-R and using vertical profiles obtained from both radiosonde and radiometer data measured during three months in summer 2008. The radiosondes are launched at Libus meteorological station in Prague, the dual band radiometer TP/WVP-3000 operates at Geodetic Observatory Pecny which is located about 25 km south-east from Libus.

2. ATMOSPHERIC PROFILING

Balloon sounding is the standard technique for retrieving vertical profiles of physical parameters of the atmosphere. Radiosondes are launched several times per day at meteorological observation sites located frequently over the world. In this work, data measured at Libus in Prague with a measurement interval of 6 hours (00, 06, 12, 18) is used to calculate the vertical profiles of water vapour density. Typical vertical profiles of water vapour (calculated from measured relative humidity) and temperature are shown in Figure 1.

Another way to get spatial information about the lower troposphere is provided by microwave radiometers. The dual band radiometer TP/WVP-3000 (temperature, pressure, water vapour), shown in Figure 2, operated at Geodetic Observatory Pecny, is designed to observe continuously an atmospheric radiation in the frequency bands 22 – 30 GHz and 51 – 59 GHz. Radiation intensities measured in 12 channels are then utilized to estimate the height profiles of temperature, water vapour and liquid water content in the atmosphere. The profiles are retrieved approximately every 10 minutes. Height resolution of the profiles is 100 meters for heights lower than 1 km and 250 meters for heights between 1 km and 10 km. Radiometer data measured during rain events is excluded from the processing described below.

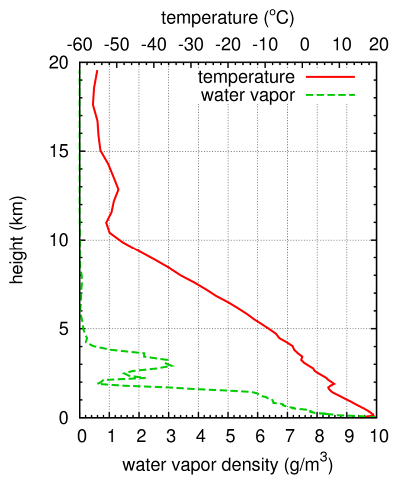

Figure 1. *Water vapour density and temperature profile obtained from radiosonde Libus measurements (July 3, 2006).*

Figure 2. *Profiling radiometer TP/WVP-3000.*

3. GAS ATTENUATION

Gas attenuation of electromagnetic waves propagating through the atmosphere is caused by molecular ab-

© Proceedings of the 8th International Symposium on Tropospheric Profiling, ISBN 978-90-6960-233-2
Delft, The Netherlands, October 2009. Editors, A. Apituley, H.W.J. Russchenberg, W.A.A. Monna

sorption. Oxygen molecules possess a magnetic moment that interacts with the magnetic field of incident electromagnetic wave resulting in absorption of its energy. Despite the concentration of water vapour in the air mixture is much less than the concentration of oxygen, it can also produce very intense levels of attenuation due to large permanent electric dipole moment of water vapour molecule. The amount of absorption is frequency selective and is described by absorption spectrum composed of discrete spectral lines. In reality, however, these lines are broadened by physical processes inside the gas that are related to its temperature and density. Most spectral lines are located on higher frequencies than radio ones, only several of them are centred lower than 350 GHz.

In radio wave propagation community, the gaseous attenuation characteristics are usually described by the coefficient of absorption γ (dB/km) also called specific attenuation [2]. This quantity is dependent on the local properties of the air. In order to get the total gaseous attenuation, the specific attenuation has to be integrated along the propagation path. ITU-R recommends a procedure for a calculation of gaseous attenuation at frequencies up to 1000 GHz [3]. Specific gaseous attenuation γ (dB/km) is a function of frequency f (GHz), temperature T (K), pressure p (hPa) and water vapour density ρ (g/m^3). Total gaseous attenuation A_{gas} (dB) of vertical atmospheric path is obtained be means of the numerical integration:

$$A_{gas} = \int_{h_{\min}}^{h_{\max}} \gamma \, \mathrm{d}h \,, \qquad (1)$$

where h_{min}, h_{max} (km) denote the minimum and maximum heights of the path considered.

In Figure 3, frequency dependence of specific gaseous attenuation for three values of water vapour density is depicted.

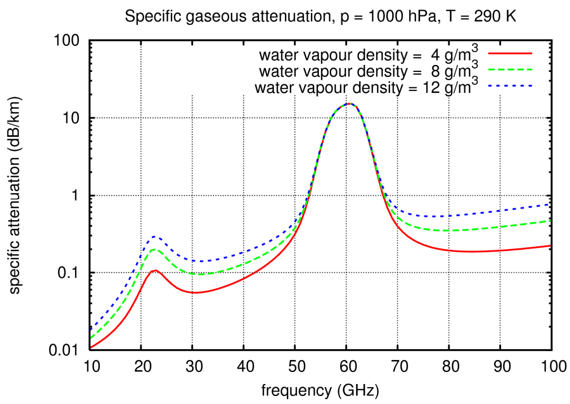

Figure 3. *Frequency dependence of specific gaseous attenuation of air for different values of water vapour density.*

The highest values of specific attenuation at around 60 GHz stem from oxygen absorption spectral lines and therefore do not vary with the water vapour content significantly. At other frequencies, however, water vapour dependence is clearly present, specific gaseous attenuation increases as water vapour density increases.

Figure 4 shows the temperature dependence of specific gaseous attenuation for several water vapour densities.

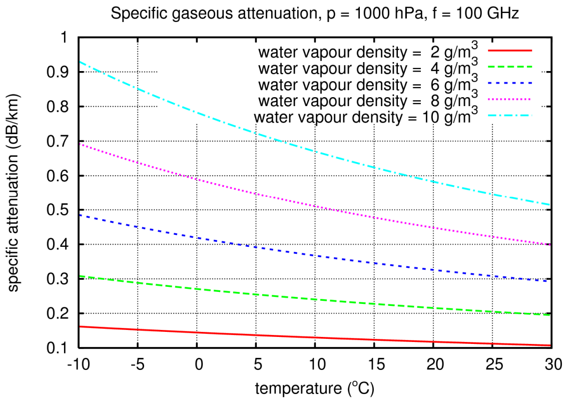

Figure 4. *Temperature dependence of specific attenuation of air for different values of water vapour density.*

Specific attenuation slightly decreases as temperature increases, but considering usual height profiles (see Figure 1) of temperature and water vapour density where the density drops down relatively quickly with increasing height, we can see that gaseous attenuation usually decreases with the height too.

4. RESULTS

The vertical profiles of pressure, temperature and water vapour density measured by radiosonde Libus and estimated by radiometer Pecny in a 3 month period of 2008 (June, July and August) are used to calculate the vertical profiles of specific gaseous attenuation. Integrating the obtained profiles according to (1), total gaseous attenuation on vertical path is obtained corresponding to every profile. Statistics of total gaseous attenuation are calculated from previous results for frequencies ranging from 10 GHz up to 100 GHz.

4.1 Single Frequency Statistics

Figure 5 shows the cumulative distribution function (CDF) of gaseous attenuation on vertical 100 GHz path obtained using atmospheric profiles measured by radiosonde Libus. Standard error of calculated CDF, $std(p)$ is estimated (assuming that the quantiles of empirical CDF follow the binomial law) as [1]:

$$std(p) = \sqrt{\frac{p(1-p)}{N}} \,, \qquad (2)$$

where p is the quantile of empirical CDF, i.e. the probability that given attenuation is exceeded and N is a number of data samples (i.e. vertical profiles) that was used to obtain the CDF. Figure 6 shows the CDF of gaseous attenuation on vertical 100 GHz path obtained using atmospheric profiles measured by radiometer Pecny. The obtained results are consistent with the radiosonde based statistics published in [4]. In Figure 7, the two CDFs are compared using Gaussian probability plot. One can see the both CDFs can be regarded as Gaussian distributions with the same variance as they are well approximated by linear lines with the same slope. Mean value difference however reaches about 0.1 dB (the relative difference of about

9%), the CDF values obtained from radiometer Pecny are smaller then CDF values obtained from radiosonde Libus.

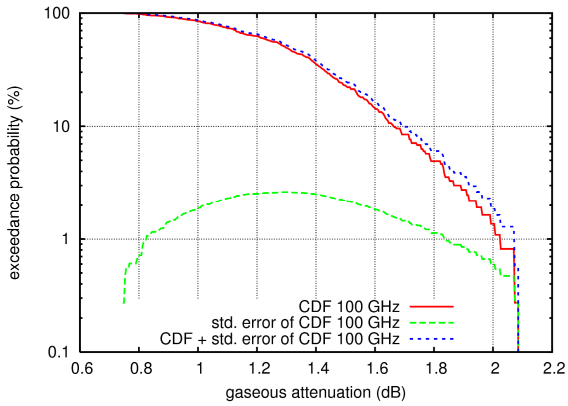

Figure 5. *Cumulative distribution of gaseous attenuation on vertical path obtained from radiosonde Libus profiles, frequency 100 GHz.*

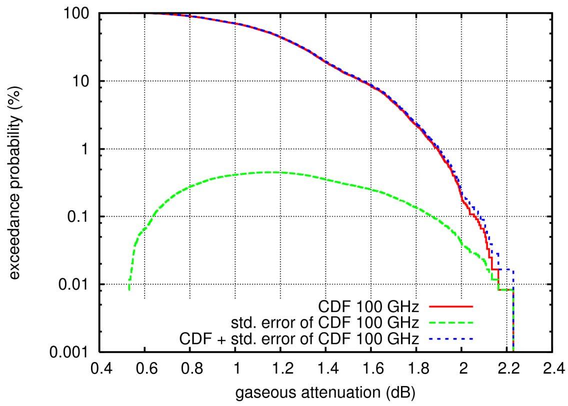

Figure 6. *Cumulative distribution of gaseous attenuation on vertical path obtained from radiometer Pecny profiles, frequency 100 GHz.*

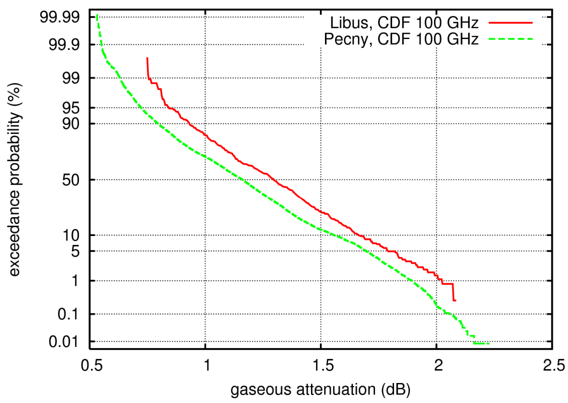

Figure 7. *Comparison of cumulative distributions of gaseous attenuation on vertical path, frequency 100 GHz.*

Since gaseous attenuation is greatly influenced by water vapour density along the propagation path at 100 GHz band, statistics of water vapour are compared too. Figure 8 shows the CDFs of integrated water vapour content in a vertical 1 square meter column that was obtained by integrating water vapour density in a similar way as in (1). Again, both CDFs can be considered being approximately Gaussian with the same variance and the mean value difference of about 1 kg/m^2 (the relative difference of about 4%).

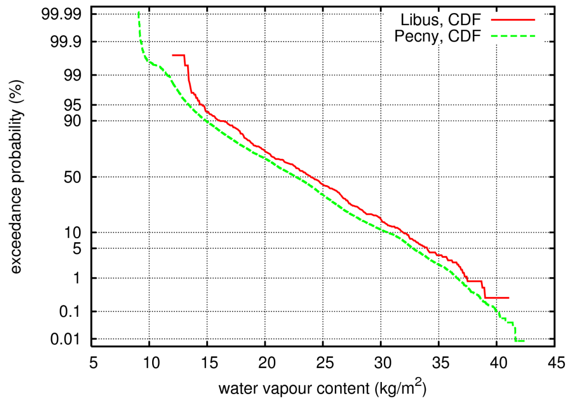

Figure 8. *Comparison of cumulative distributions of water vapour content on vertical path obtained from radiosonde Libus and radiometer Pecny.*

4.2 Frequency Dependence

Figures 9 and 10 show the frequency characteristics of gaseous attenuation statistics obtained from radiosonde and radiometer profiles. In Figure 11, median values at different frequencies are compared. It is seen the relative difference of medians is about 10% at most frequencies between 10 and 100 GHz with two notable exceptions, the first being around 22/23 GHz where the relative difference is lower and the second around 60 GHz where the relative difference of the two medians is larger than 10%.

Since the mean (or median) values of gaseous attenuation change strongly with the frequency within several orders of magnitude, it is suitable to express the fluctuations of gaseous attenuation around its mean by a relative standard deviation, *RSD* (%):

$$RSD = \left| \frac{\sigma}{\mu} \right| \cdot 100\% \,, \tag{3}$$

where μ is a mean value and σ is a standard deviation. Figure 12 shows the frequency dependence of *RSD* of gaseous attenuation obtained using the radiosonde and radiometer profiles. The fluctuations of gaseous attenuation relative to the mean value are higher in the frequency bands 20 – 30 GHz and >80 GHz where the gaseous attenuation is mainly due to water vapour absorption. It is because the water vapour density in lower troposphere changes significantly during a 3 month period. On the other hand, large attenuation in 60 GHz band is relatively stable, because it is caused by oxygen absorption, oxygen content being quite stable in the air mixture. The same pattern is followed by gaseous attenuation statistics obtained from both the radiosonde and the radiometer as can be seen in Figure 12.

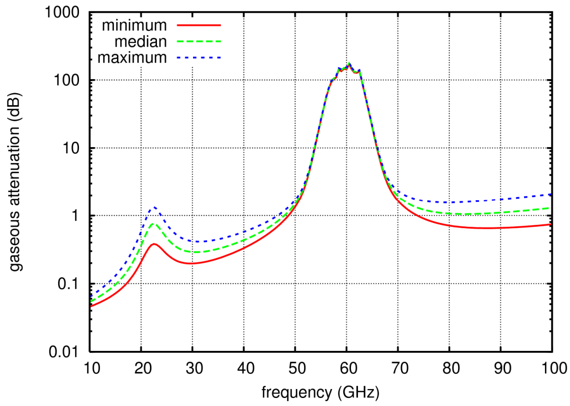

Figure 9. *Frequency dependence of gaseous attenuation statistics on vertical path obtained from radiosonde Libus profiles.*

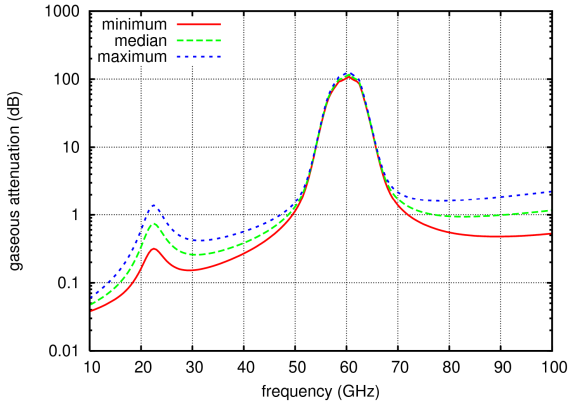

Figure 10. *Frequency dependence of gaseous attenuation statistics on vertical path obtained from radiometer Pecny profiles.*

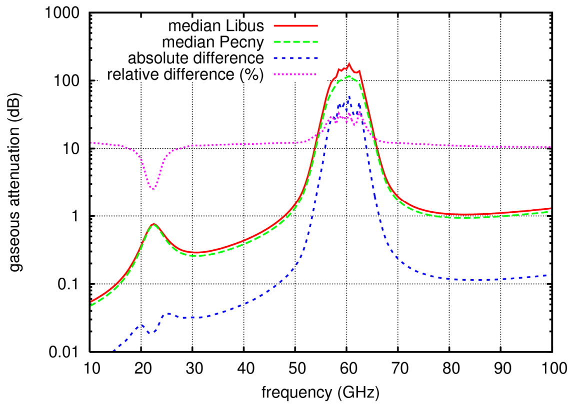

Figure 11. *Comparison of frequency dependence of gaseous attenuation median obtained from radiosonde Libus and radiometer Pecny.*

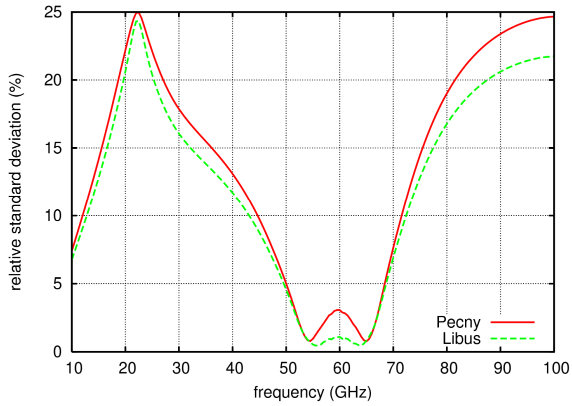

Figure 12. *Comparison of relative standard deviation of gaseous attenuation obtained from radiosonde Libus and radiometer Pecny.*

5. CONCLUSION

Gaseous attenuation statistics obtained from vertical atmospheric profiles measured by radiosonde and by a ground based radiometer during 3 months in summer 2008 were compared. It was demonstrated that both tools give comparable gaseous attenuation statistics both having Gaussian distribution with the same variance and with median value relative difference of about 10% at most of 10-100 GHz frequency band. The obtained results suggest that water vapour profiling using radiometer can be utilized for gaseous attenuation statistics estimation with an advantage of higher temporal resolution compared to radiosondes.

ACKNOWLEDGEMENT

Ministry of Education, Youth and Sports of the Czech Republic under the Projects No. OC093 in the framework of COST 297 and No. OC09076 in the framework of COST IC0802 financially supported this contribution.

The authors would like to thank the Czech Hydrometeorological Institute for providing radiosonde data.

REFERENCES

[1] Lavergnat J., Sylvain M., 2000: *Radio Wave Propagation*, Wiley.

[2] Brussaard G., et al., 1996: *Handbook on Radiometeorology*, ITU.

[3] Rec. ITU-R P.676-6, 2008: Attenuation by atmospheric gases, ITU.

[4] Fišer O., 1996: Prediction of Rain and Water Vapour Attenuation at Frequencies 10-30 GHz, *Radioengineering*, **5**, No. 3, pp. 18-22.