International Telecommunication Union

ITU-R

Radiocommunication Sector of ITU

Recommendation ITU-R P.840-7

(12/2017)

Attenuation due to clouds and fog

P Series

Radiowave propagation

International Telecommunication Union

Foreword

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Series	Title
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BR	Recording for production, archival and play-out; film for television
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BT	Broadcasting service (television)
F	Fixed service
M	Mobile, radiodetermination, amateur and related satellite services
P	**Radiowave propagation**
RA	Radio astronomy
RS	Remote sensing systems
S	Fixed-satellite service
SA	Space applications and meteorology
SF	Frequency sharing and coordination between fixed-satellite and fixed service systems
SM	Spectrum management
SNG	Satellite news gathering
TF	Time signals and frequency standards emissions
V	Vocabulary and related subjects

Note*: This ITU-R Recommendation was approved in English under the procedure detailed in Resolution ITU-R 1.*

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RECOMMENDATION ITU-R P.840-7

Attenuation due to clouds and fog

(Question ITU-R 201/3)

(1992-1994-1997-1999-2009-2012-2013-2017)

Scope

This Recommendation provides methods to predict the attenuation due to clouds and fog on Earth-space paths.

The ITU Radiocommunication Assembly,

considering

a) that there is a need to give guidance to engineers in the design of Earth-space telecommunication systems for frequencies higher than 10 GHz;

b) that attenuation due to clouds may be a factor of importance especially for microwave systems well above 10 GHz or low-availability systems;

c) that for the calculation of the time series of total attenuation and space-time prediction methods, an analytical expression for the statistics of the total columnar content of cloud liquid water is needed;

d) that local measured data of the total columnar content of cloud liquid water may not be available,

recommends

1 that if local measured data of the total columnar content of cloud liquid water is not available, the method given in § 3.1 of Annex 1 should be used for the prediction of the attenuation due to clouds and fog;

2 that if local measured data of the total columnar content of cloud liquid water is available, the method given in § 3.2 of Annex 1 should be used for the calculation of the attenuation due to clouds;

3 that the information in § 4 of Annex 1 should be used for global calculations of propagation effects, required by, *inter alia*, space-time channel models, that require an analytic expression for the statistics of the total columnar content of cloud liquid water.

Annex 1

1 Introduction

For clouds or fog consisting entirely of small droplets, generally less than 0.01 cm, the Rayleigh approximation is valid for frequencies up to 200 GHz, and the specific attenuation within a cloud or fog can be written as:

$$\gamma_c(f,T) = K_l(f,T)M \qquad \text{(dB/km)} \tag{1}$$

where:

- γ_c: specific attenuation (dB/km) within the cloud
- K_l: cloud liquid water specific attenuation coefficient ((dB/km)/(g/m^3))
- M: liquid water density in the cloud or fog (g/m^3)
- f: frequency (GHz)
- T: cloud liquid water temperature (K).

At frequencies of the order of 100 GHz and above, attenuation due to fog may be significant. The liquid water density in fog is typically about 0.05 g/m^3 for medium fog (visibility of the order of 300 m) and 0.5 g/m^3 for thick fog (visibility of the order of 50 m).

2 Cloud liquid water specific attenuation coefficient

A mathematical model based on Rayleigh scattering, which uses a double-Debye model for the dielectric permittivity $\varepsilon(f)$ of water, can be used to calculate the value of K_l for frequencies up to 200 GHz:

$$K_l(f,T) = \frac{0.819f}{\varepsilon''(1+\eta^2)} \qquad \text{(dB/km)/(g/m}^3\text{)} \tag{2}$$

where f is the frequency (GHz), and:

$$\eta = \frac{2+\varepsilon'}{\varepsilon''} \tag{3}$$

The complex dielectric permittivity of water is given by:

$$\varepsilon''(f) = \frac{f(\varepsilon_0-\varepsilon_1)}{f_p\left[1+(f/f_p)^2\right]} + \frac{f(\varepsilon_1-\varepsilon_2)}{f_s\left[1+(f/f_s)^2\right]} \tag{4}$$

$$\varepsilon'(f) = \frac{\varepsilon_0-\varepsilon_1}{\left[1+(f/f_p)^2\right]} + \frac{\varepsilon_1-\varepsilon_2}{\left[1+(f/f_s)^2\right]} + \varepsilon_2 \tag{5}$$

where:

$$\varepsilon_0 = 77.66 + 103.3(\theta - 1) \tag{6}$$

$$\varepsilon_1 = 0.0671\varepsilon_0 \tag{7}$$

$$\varepsilon_2 = 3.52 \tag{8}$$

$$\theta = 300 / T \tag{9}$$

and T is the liquid water temperature (K).

The principal relaxation frequency, f_p, and secondary relaxation frequency, f_s, are:

$$f_p = 20.20 - 146(\theta - 1) + 316(\theta - 1)^2 \qquad \text{(GHz)} \tag{10}$$

$$f_s = 39.8 f_p \qquad \text{(GHz)} \tag{11}$$

3 Cloud attenuation along slant paths

If local measured data of the total columnar content of cloud liquid water, L (kg/m^2 or, equivalently, mm), is not available, the method in § 3.1 should be used to predict the cloud attenuation along slant paths. This prediction method is based on ERA-40 data where the total columnar content of cloud liquid water reduced to a fixed temperature of 273.15 K, L_{red} (kg/m^2 or, equivalently, mm), is used.

If local measured data of the total columnar content of cloud liquid water, L, is available from other sources, e.g. from ground radiometric measurements, Earth observation products or meteorological numerical products, the method in § 3.2 should be used to calculate the cloud attenuation along slant-paths.

3.1 Distribution of cloud attenuation along slant paths based on global digital maps

The slant path cloud attenuation, A, for a given probability, p, is:

$$A = \frac{L_{red}\, K_l\left(f, 273.15\right)}{\sin \varphi} \qquad \text{(dB)} \quad \text{for} \quad 90° \geq \varphi \geq 5° \tag{12}$$

where L_{red} is the total columnar content of liquid water reduced to a temperature of 273.15 K, L_{red} (kg/m^2 or, equivalently, mm) at the probability p, φ is the elevation angle, and K_l is calculated using equations (2) to (11) for a water temperature of 273.15 K.

The annual values of total columnar content of reduced cloud liquid water, L_{red} (kg/m^2), exceeded for the probability levels of 0.1, 0.2, 0.3, 0.5, 1, 2, 3, 5, 10, 20, 30, 50, 60, 70, 80, 90, 95 and 99% of an average year are an integral part of this Recommendation and are available in the form of digital maps.

The monthly values of total columnar content of reduced cloud liquid water, L_{red} (kg/m^2), exceeded for the probability levels of 1, 2, 3, 5, 10, 20, 30, 50, 60, 70, 80, 90, 95 and 99% of each average month are an integral part of this Recommendation and are available in the form of digital maps.

These digital maps are available in the Supplement file R-REC-P.840-7-Maps.zip.

The data is from 0° to 360° in longitude and from +90° to –90° in latitude, with a resolution of 1.125º in both latitude and longitude.

The total columnar content of reduced cloud liquid water at any desired location on the surface of the Earth can be derived by the following interpolation method:

a) determine the two probabilities, p_{above} and p_{below}, above and below the desired probability, p, from the set: 0.1, 0.2, 0.3, 0.5, 1, 2, 3, 5, 10, 20, 30, 50, 60, 70, 80, 90, 95 and 99% for annual statistics and from the set: 1, 2, 3, 5, 10, 20, 30, 50, 60, 70, 80, 90, 95 and 99% for monthly statistics;

b) for the two probabilities, p_{above} and p_{below}, determine the total columnar content of reduced cloud liquid water, L_{red1}, L_{red2}, L_{red3} and L_{red4} at the four closest grid points;

c) determine the total columnar content of reduced cloud liquid water, $L_{redabove}$ and $L_{redbelow}$, at the probabilities, p_{above} and p_{below}, by performing a bi-linear interpolation of the four values of total columnar content of reduced cloud liquid water, L_{red1}, L_{red2}, L_{red3} and L_{red4} at the four grid points, as described in Recommendation ITU-R P.1144;

d) determine the total columnar content of reduced cloud liquid water, L_{red}, at the desired probability, p, by interpolating $L_{redabove}$ and $L_{redbelow}$ vs. p_{above} and p_{below} to p on a linear L_{red} vs. log p scale.

3.2 Cloud attenuation along slant paths based on local data

The slant path cloud attenuation, A, is:

$$A = \frac{L K_l^*(f, 273.15)}{\sin\varphi} \qquad \text{(dB)} \qquad \text{for} \quad 90° \geq \varphi \geq 5° \tag{13}$$

where L is the total columnar content of liquid water (kg/m^2 or, equivalently, mm), φ is the elevation angle, and K_l^* is calculated as follow:

$$K_l^*(f, T) = \frac{0.819\left(1.9479 \times 10^{-4} f^{2.308} + 2.9424 f^{0.7436} - 4.9451\right)}{\varepsilon''(1+\eta^2)} \qquad \text{(dB/km)/(g/m}^3\text{)} \tag{14}$$

where η is given in equation (3), ε'' is given in equation (4), and the liquid water temperature, T, is 273.15 K.

4 Approximation of L_{red} by a log-normal distribution

The annual statistics of the total columnar content of reduced cloud liquid water content can be approximated by a log-normal distribution. The digital maps of mean, m, standard deviation, σ, and probability of non-zero reduced total columnar content of cloud liquid water, P_{clw}, parameters of the log-normal distribution are an integral part of this Recommendation.

The total columnar content of reduced cloud liquid water at any desired location on the surface of the Earth can be derived by the following interpolation method:

a) determine the parameters, m_1, m_2, m_3, m_4, σ_1, σ_2, σ_3, σ_4, P_{CLW1}, P_{CLW2}, P_{CLW3} and P_{CLW4} at the four closest grid points;

b) determine the total columnar content of reduced cloud liquid water L_{red1}, L_{red2}, L_{red3}, and L_{red4} for the desired probability, p, at the four closest grid points from the parameters m_1, m_2, m_3, m_4, σ_1, σ_2, σ_3, σ_4, P_{CLW1}, P_{CLW2}, P_{CLW3} and P_{CLW4} as follows:

$$L_{red,i} = \mathrm{e}^{m_i + \sigma_i Q^{-1}\left(\frac{P}{P_{CLWi}}\right)} \qquad \text{for } i = 1, 2, 3, 4 \tag{15}$$

where:

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^{\infty} \mathrm{e}^{-\frac{t^2}{2}} \mathrm{d}t \tag{16}$$

c) determine the total columnar content of reduced cloud liquid water at the desired location by performing a bi-linear interpolation of the four values of total columnar content of reduced cloud liquid water, L_{red1}, L_{red2}, L_{red3}, and L_{red4} at the four grid points as described in Recommendation ITU-R P.1144.

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