ITUPublications
Recommendations

International Telecommunication Union
Radiocommunication Sector

Recommendation ITU-R P.840-9

(08/2023)

P Series: Radiowave propagation

Attenuation due to clouds and fog

Foreword

The role of the Radiocommunication Sector is to ensure the rational, equitable, efficient and economical use of the radio-frequency spectrum by all radiocommunication services, including satellite services, and carry out studies without limit of frequency range on the basis of which Recommendations are adopted.

The regulatory and policy functions of the Radiocommunication Sector are performed by World and Regional Radiocommunication Conferences and Radiocommunication Assemblies supported by Study Groups.

Policy on Intellectual Property Right (IPR)

ITU-R policy on IPR is described in the Common Patent Policy for ITU-T/ITU-R/ISO/IEC referenced in Resolution ITU-R 1. Forms to be used for the submission of patent statements and licensing declarations by patent holders are available from http://www.itu.int/ITU-R/go/patents/en where the Guidelines for Implementation of the Common Patent Policy for ITU-T/ITU-R/ISO/IEC and the ITU-R patent information database can also be found.

Series of ITU-R Recommendations

(Also available online at https://www.itu.int/publ/R-REC/en)

Series	Title
BO	Satellite delivery
BR	Recording for production, archival and play-out; film for television
BS	Broadcasting service (sound)
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.*

Electronic Publication
Geneva, 2023

RECOMMENDATION ITU-R P.840-9

Attenuation due to clouds and fog

(Question ITU-R 201/3)

(1992-1994-1997-1999-2009-2012-2013-2017-2019-2023)

Scope

This Recommendation provides:

a) a method to estimate the instantaneous slant path cloud attenuation for the frequency range from 1 to 200 GHz when the instantaneous integrated cloud liquid water content[1] is known from local data, a reference profile, or referenced digital maps;

b) a method to estimate the statistics of slant path cloud attenuation for the frequency range from 1 to 200 GHz when the integrated cloud liquid water content statistics are known either from local data, a reference profile, or referenced digital maps;

c) a log-normal approximation to the slant path cloud attenuation for use in Recommendation ITU-R P.1853.

Keywords

Cloud attenuation, cloud liquid water content, integrated columnar cloud liquid water content, cloud liquid specific attenuation

Acronyms/Abbreviations/Glossary

ASCII	American Standard Code for Information Interchange
CCDF	Complementary cumulative distribution function
ECMWF	European Centre for Medium-Range Weather Forecasts

Related ITU-R Recommendations and Handbook

Recommendation ITU-R P.530

Recommendation ITU-R P.618

Recommendation ITU-R P.619

Recommendation ITU-R P.840

Recommendation ITU-R P.1853

Recommendation ITU-R P.2041

Recommendation ITU-R P.2145

Handbook on Radiometeorology

NOTE – In every case, the latest revision/edition of the Recommendation in force should be used.

---

[1] The integrated cloud liquid water content is the total amount of cloud liquid water in a vertical column extending from the surface of the Earth to the top of the atmosphere. The terms integrated cloud liquid water content, total cloud liquid water content, total column(ar) cloud liquid water, integrated columnar cloud liquid water content, and total columnar content of cloud liquid water are synonymous.

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 a log-normal approximation to the slant path cloud attenuation for use in Recommendation ITU-R P.1853 is needed;

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

e) that data from Numerical Weather Prediction systems can provide information about cloud parameters,

recommends

1 that, for instantaneous values of integrated cloud liquid water content known from local data, the method in § 3.1 should be used to estimate the instantaneous slant path cloud attenuation for the frequency range from 1 to 200 GHz;

2 that, for values of integrated cloud liquid water content statistics known from long-term historical data or from the maps in § 4, the method in § 3.2 should be used to estimate statistics of the slant path cloud attenuation for the frequency range from 1 to 200 GHz;

3 that, for use in Recommendation ITU-R P.1853, the method in § 3.3 should be used to estimate the log-normal approximation to the slant path cloud attenuation.

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:

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

where:

- γ_c: specific attenuation (dB/km) within the cloud
- K_l: cloud liquid water specific attenuation coefficient ((dB/km)/(g/m^3))
- ρ_l: 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:

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

where f is the frequency (GHz), and:

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

The complex dielectric permittivity of water is given by:

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

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

where:

$$\varepsilon_0 = 77.66 + 103.3\left(\frac{300}{T}-1\right) \tag{6}$$

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

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

and T is the liquid water temperature (K).

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

$$f_p = 20.20 - 146\left(\frac{300}{T}-1\right) + 316\left(\frac{300}{T}-1\right)^2 \qquad \text{(GHz)} \tag{9}$$

$$f_s = 39.8f_p \qquad \text{(GHz)} \tag{10}$$

3 Slant path cloud attenuation prediction method

There are three prediction methods of the slant path cloud attenuation:

1) As described in § 3.1, an instantaneous prediction method, when the integrated cloud liquid water content is known from instantaneous local measured data;

2) As described in § 3.2, a statistical prediction method, when the statistics of integrated cloud liquid water content are known, either from:

   a) local data or;

   b) from the integral maps at the desired location in § 4.1;

3) As described in § 3.3, the log-normal approximation to the slant path statistical prediction method, where the log-normal mean and standard deviation parameters are known, either from:

   a) local data or;

   b) from the integral maps at the desired location in § 4.1.

3.1 Slant path instantaneous cloud attenuation prediction method

The predicted slant path instantaneous cloud attenuation, A_C, is:

$$A_C(f) = \frac{K_L(f) \cdot L}{\sin\theta} \qquad \text{(dB)} \tag{11}$$

where:

- f : frequency of interest, in GHz
- K_L : cloud liquid mass absorption coefficient in dB/(kg/m^2) or dB/mm
- L : integrated cloud liquid water content, in kg/m^2 or mm, from the surface of the Earth at the desired location
- θ : elevation angle.

and

$$K_L(f) = K_l(f, T = 273.75K) \cdot \left(A_1 e^{-\frac{(f-f_1)^2}{\sigma_1}} + A_2 e^{-\frac{(f-f_2)^2}{\sigma_2}} + A_3 \right) \tag{12}$$

with:

$$\begin{cases} A_1 = 0.1522, A_2 = 11.51, A_3 = -10.4912 \\ f_1 = -23.9589, f_2 = 219.2096 \\ \sigma_1 = 3.2991 \times 10^3, \sigma_2 = 2.7595 \times 10^6 \end{cases}$$

3.2 Slant path statistical cloud attenuation prediction method

The predicted slant path statistical cloud attenuation, A_C, is:

$$A_C(f,p) = \frac{K_L(f) \cdot L(p)}{\sin\theta} \qquad \text{(dB)} \tag{13}$$

where:

- f : frequency of interest, in GHz
- K_L : cloud liquid mass absorption coefficient in dB/(kg/m^2) or dB/mm
- p : exceedance probability (CCDF) of interest, in %
- $L(p)$: integrated cloud liquid water content at the exceedance probability p, in kg/m^2 or mm, from the surface of the Earth at the desired location
- θ : elevation angle.

and

$$K_L(f) = K_l(f, T = 273.75K) \cdot \left(A_1 e^{-\frac{(f-f_1)^2}{\sigma_1}} + A_2 e^{-\frac{(f-f_2)^2}{\sigma_2}} + A_3 \right) \tag{14}$$

with:

$$\begin{cases} A_1 = 0.1522, A_2 = 11.51, A_3 = -10.4912 \\ f_1 = -23.9589, f_2 = 219.2096 \\ \sigma_1 = 3.2991 \times 10^3, \sigma_2 = 2.7595 \times 10^6 \end{cases}$$

3.3 Log-normal approximation to the slant path statistical cloud attenuation

The log-normal approximation to the predicted slant path statistical cloud attenuation, A_c, is:

$$A_c(f,p) = \begin{cases} \dfrac{K_L(f) e^{m_L + \sigma_L Q^{-1}\left(\frac{p}{P_L}\right)}}{\sin\theta} & \text{for } p < P_L \\ 0 & \text{for } p \geq P_L \end{cases} \qquad \text{(dB)} \tag{15}$$

where:

f :	frequency of interest, in GHz
p :	exceedance probability (CCDF) of interest, in %
m_L :	log-normal mean parameter at the desired location
s_L :	log-normal standard deviation parameter at the desired location
P_L :	probability of cloud at the desired location, in %
θ :	elevation angle
$Q^{-1}(x)$:	inverse standard normal complementary cumulative distribution function defined in Recommendation ITU-R P.1057.

and

$$K_L(f) = K_l(f, T = 273.75K) \cdot \left(A_1 e^{-\frac{(f-f_1)^2}{\sigma_1}} + A_2 e^{-\frac{(f-f_2)^2}{\sigma_2}} + A_3 \right) \quad (16)$$

with:

$$\begin{cases} A_1 = 0.1522, A_2 = 11.51, A_3 = -10.4912 \\ f_1 = -23.9589, f_2 = 219.2096 \\ \sigma_1 = 3.2991 \times 10^3, \sigma_2 = 2.7595 \times 10^6 \end{cases}$$

NOTE – If the desired location is at a grid point of the digital map of P_L where $P_L \leq 0.02$, then $A_c(f,p) = 0$ dB; if the desired location is between grid points of the digital map of P_L where $P_L \leq 0.02$ at any of the four surrounding grid points, then $A_c(f,p) = 0$ dB.

4 Digital maps related to the calculation of cloud attenuation

4.1 Annual and monthly meteorological statistical parameters

Digital maps of worldwide annual and monthly statistics of integrated cloud liquid water content, L, in kg/m^2, or, equivalently, mm, are an integral part of this Recommendation and can be found in the additional parts of this Recommendation.

Digital maps of the worldwide annual statistics of integrated cloud liquid water content, L, approximated by a log-normal distribution are an integral part of this Recommendation and can be found in the additional parts of this Recommendation.

4.2 Interpolation

Section 4.2.1 provides the statistical and spatial interpolation method to calculate the annual and monthly integrated cloud liquid water content vs exceedance probability (CCDF) at any desired location on the surface of the Earth.

Section 4.2.2 provides a statistical and spatial interpolation method to calculate the annual and monthly mean and standard deviation of integrated cloud liquid water content, and log-normal integrated cloud liquid water content mean and standard deviation parameters at any desired location on the surface of the Earth.

4.2.1 Spatial and statistical (CCDF) interpolation

The annual or monthly integrated cloud liquid water content statistics, $L(p)$, at any desired location on the surface of the Earth and exceedance probability (CCDF), p, within the exceedance probability range of the integral digital maps can be calculated using the following interpolation method:

a) determine the two exceedance probabilities, p_{above} and p_{below}, above and below the desired exceedance probability, p, from the set: 0.01, 0.02, 0.03, 0.05, 0.1, 0.2, 0.3, 0.5, 1, 2, 3, 5, 10, 20, 30, 50, 60, 70, 80, 90, 95, 99, and 100% for annual statistics and from the set: 0.1, 0.2, 0.3, 0.5, 1, 2, 3, 5, 10, 20, 30, 50, 60, 70, 80, 90, 95, 99 and 100% for monthly statistics;

b) for each of the four surrounding grid points, i = 1, 2, 3, and 4, and for the two exceedance probabilities, p_{above} and p_{below}, determine the integrated cloud liquid water content, L_i, from the appropriate annual or monthly map of $L(p)$;

c) determine L_{above} and L_{below} at the desired location and the two probabilities p_{above} and p_{below} by performing a bilinear interpolation of L_i, i = 1, 2, 3, and 4 at the four surrounding grid points using the bilinear interpolation method specified in Annex 1 of Recommendation ITU-R P.1144;

d) determine the integrated cloud liquid water content, L, at the desired location and exceedance probability, p, by interpolating L_{above} and L_{below} vs. p_{above} and p_{below} to p on a linear L vs. $\log_{10} p$ scale.

4.2.2 Spatial and statistical (mean and standard deviation) interpolation

The monthly or annual mean or standard deviation of integrated cloud liquid water content, $\bar{L}$ or σ_L, annual log-normal integrated cloud liquid water content mean or standard deviation parameter, m_L or σ_L, or annual probability of cloud, P_L, at any desired location on the surface of the Earth can be calculated using the bilinear interpolation method specified in Annex 1 to Recommendation ITU-R P.1144, at the four surrounding points of the desired parameter of interest X, where $X = \bar{L}$, σ_L, m_L, s_L or P_L at the desired location.