International Telecommunication Union

ITU-R

Radiocommunication Sector of ITU

Recommendation ITU-R P.840-4

(10/2009)

Attenuation due to clouds and fog

P Series

Radiowave propagation

International Telecommunication Union

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.

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Series of ITU-R Recommendations

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

Series	Title
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M	Mobile, radiodetermination, amateur and related satellite services
P	**Radiowave propagation**
RA	Radio astronomy
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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.840-4

Attenuation due to clouds and fog

(Question ITU-R 201/3)

(1992-1994-1997-1999-2009)

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,

recommends

1 that the curves, models and maps given in Annex 1 should be used for the calculation of attenuation due to clouds and fog;

2 that the information in 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 below 200 GHz and it is possible to express the attenuation in terms of the total water content per unit volume. Thus the specific attenuation within a cloud or fog can be written as:

$$\gamma_c = K_l M \qquad \text{dB/km} \tag{1}$$

where:

γ_c: specific attenuation (dB/km) within the cloud

K_l: specific attenuation coefficient ((dB/km)/(g/m^3))

M: liquid water density in the cloud or fog (g/m^3).

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 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 1 000 GHz:

$$K_l = \frac{0.819 f}{\varepsilon''(1+\eta^2)} \qquad \text{(dB/km)/(g/m}^3\text{)} \tag{2}$$

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:

$$\varepsilon_0 = 77.6 + 103.3\,(\theta - 1) \tag{6}$$

$$\varepsilon_1 = 5.48 \tag{7}$$

$$\varepsilon_2 = 3.51 \tag{8}$$

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

with T the temperature (K).

The principal and secondary relaxation frequencies are:

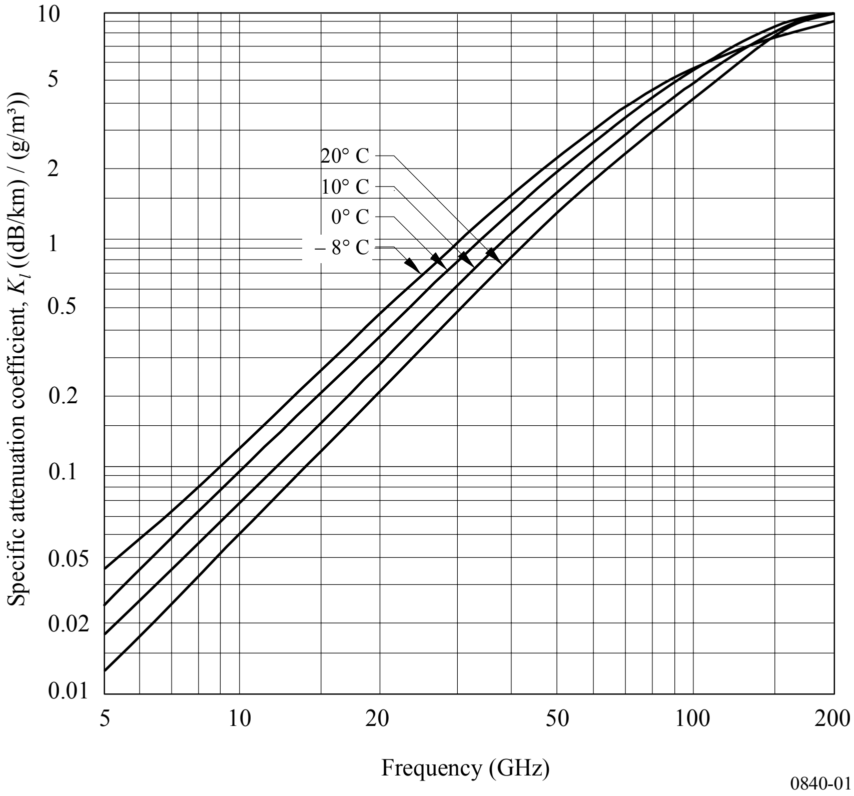
$$f_p = 20.09 - 142\,(\theta - 1) + 294\,(\theta - 1)^2 \qquad \text{GHz} \tag{10}$$

$$f_s = 590 - 1\,500\,(\theta - 1) \qquad \text{GHz} \tag{11}$$

Figure 1 shows the values of K_l at frequencies from 5 to 200 GHz and temperatures between –8° C and 20° C. For cloud attenuations, the curve corresponding to 0° C should be used.

FIGURE 1

Specific attenuation by water droplets at various temperatures as function of frequency



3 Cloud attenuation

To obtain the attenuation due to clouds for a given probability, the statistics of the total columnar content of liquid water L (kg/m^2) or, equivalently, mm of precipitable water for a given site must be known yielding:

$$A = \frac{L K_l}{\sin\theta} \qquad \text{dB} \quad \text{for} \quad 90° \geq \theta \geq 5° \qquad (12)$$

where θ is the elevation angle and K_l is read from Fig. 1. Note that K_l is identical to the mass absorption coefficient a_L introduced in Recommendation ITU-R P.836, equation (1).

Statistics of the total columnar content of liquid water may be obtained from radiometric measurements or from radiosonde launches.

4 Total columnar content of cloud liquid water

The total columnar content of cloud liquid water, expressed in kg/m^2 or, equivalently, in mm of liquid water, can be obtained from radiosonde soundings and radiometric measurements. Radiosonde data is widely available; however, it has limited time resolution and is only applicable to zenith paths. The total columnar content of cloud liquid water can be retrieved from radiometric measurements at appropriate frequencies along the desired path.

The annual values of total columnar content of cloud liquid water, L (kg/m^2), exceeded for 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 available in the form of digital maps from the Radiocommunication Study Group 3 website, in the data files ESAWRED_xx_v4.TXT, where xx = 01, 02, 03, 05, 1, 2, 3, 5, 10, 20, 30, 50, 60, 70, 80, 90, 95 and 99. 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. This data is to be used in conjunction with the companion data files ESALAT_1dot125.TXT and ESALON_1dot125.TXT containing the latitudes and longitudes of the corresponding entries (grid points) in data files ESAWRED_xx_v4.TXT. The total columnar content of 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%;

b) for the two probabilities, p_{above} and p_{below}, determine the total columnar water vapour content, V_1, V_2, V_3, and V_4 at the four closest grid points;

c) determine the total columnar content of cloud liquid water, L_{above} and L_{below}, at the probabilities, p_{above} and p_{below}, by performing a bi-linear interpolation of the four values of total columnar content of cloud liquid water, L_1, L_2, L_3, and L_4 at the four grid points, as described in Recommendation ITU-R P.1144;

d) determine the total columnar water vapour content, L, at the desired probability, p, by interpolating L_{above} and L_{below} vs. p_{above} and p_{below} to p on a linear L vs. log p scale.

Note that the digital maps of total columnar content of cloud liquid water contain the symbol NaN (Not-a-Number) when there is no value of the total water vapour content corresponding to a given annual probability of exceedance.

Example contours of total columnar content of cloud liquid water are provided in Figs. 2, 3, 4, 5, 6, and 7 for exceedance probabilities of 0.1, 0.5, 1, 5, 10 and 20%.

FIGURE 2

Normalized total columnar content of cloud liquid water (kg/m^2) exceeded for 0.1% of the year

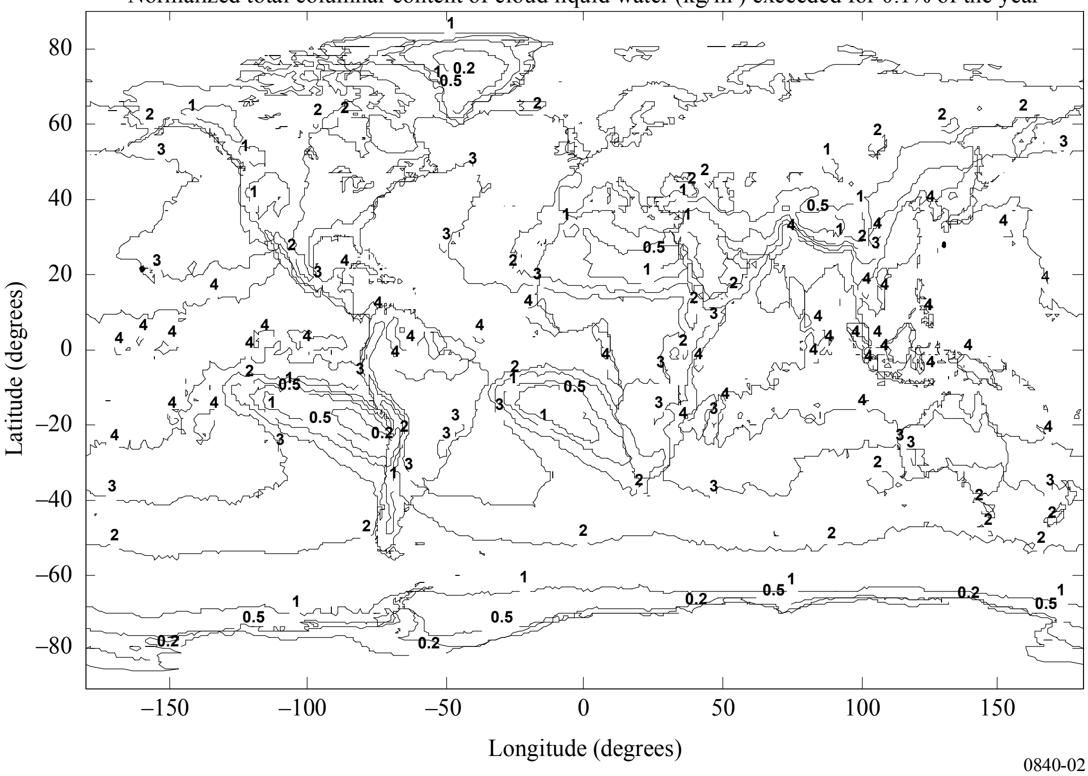


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FIGURE 3

Normalized total columnar content of cloud liquid water (kg/m^2) exceeded for 0.5% of the year

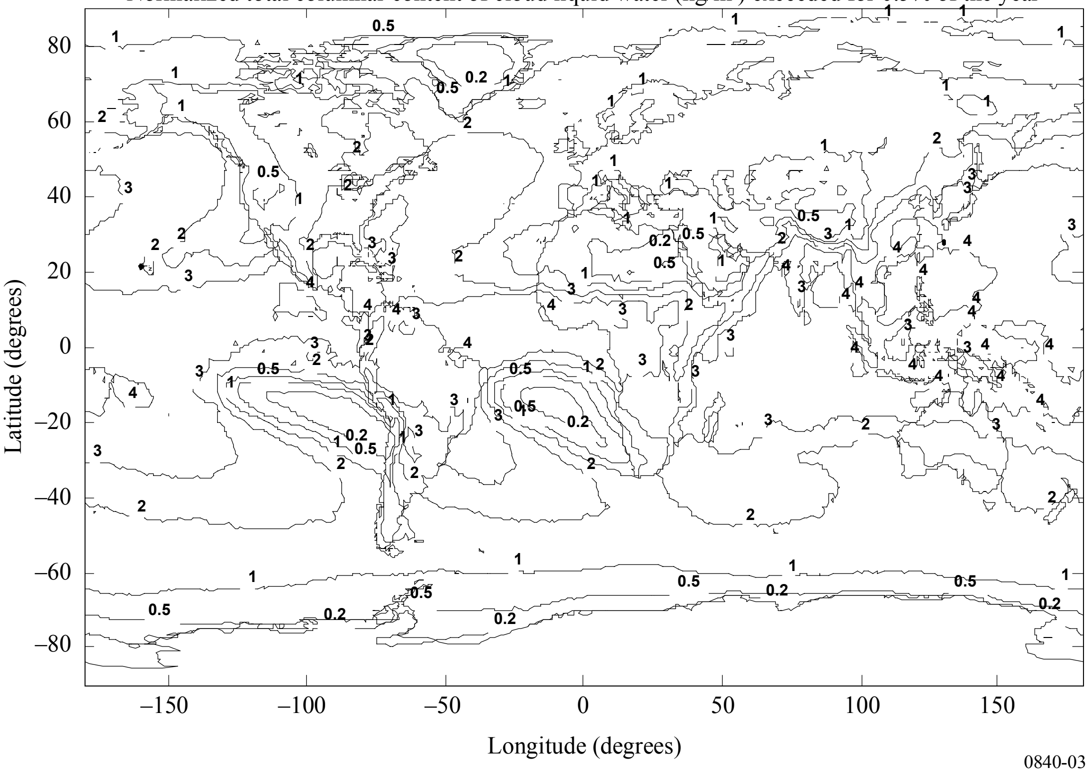

FIGURE 4

Normalized total columnar content of cloud liquid water (kg/m^2) exceeded for 1% of the year

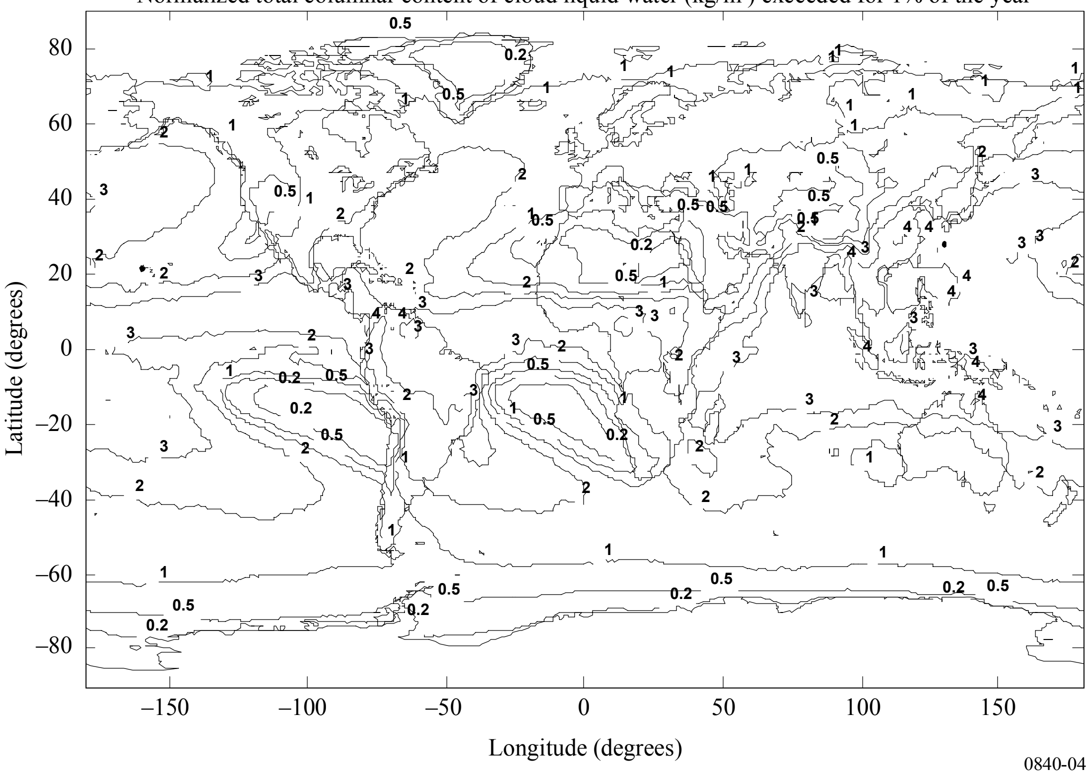

FIGURE 5

Normalized total columnar content of cloud liquid water (kg/m^2) exceeded for 5% of the year

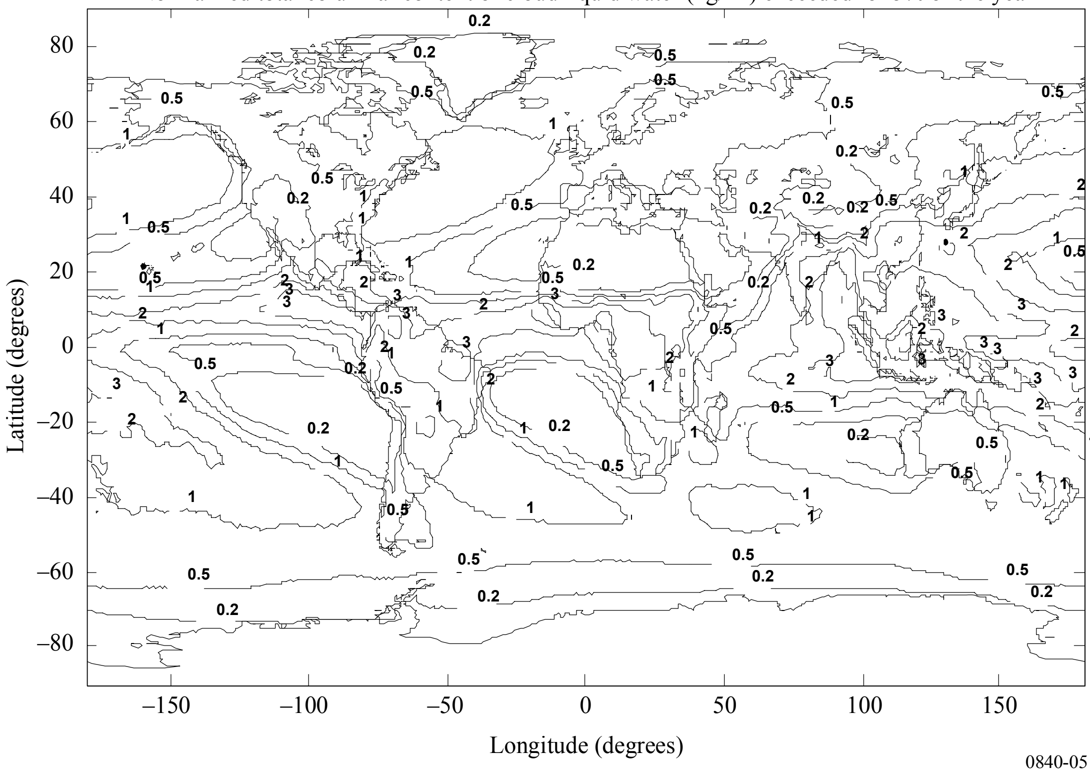

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FIGURE 6

Normalized total columnar content of cloud liquid water (kg/m^2) exceeded for 10% of the year

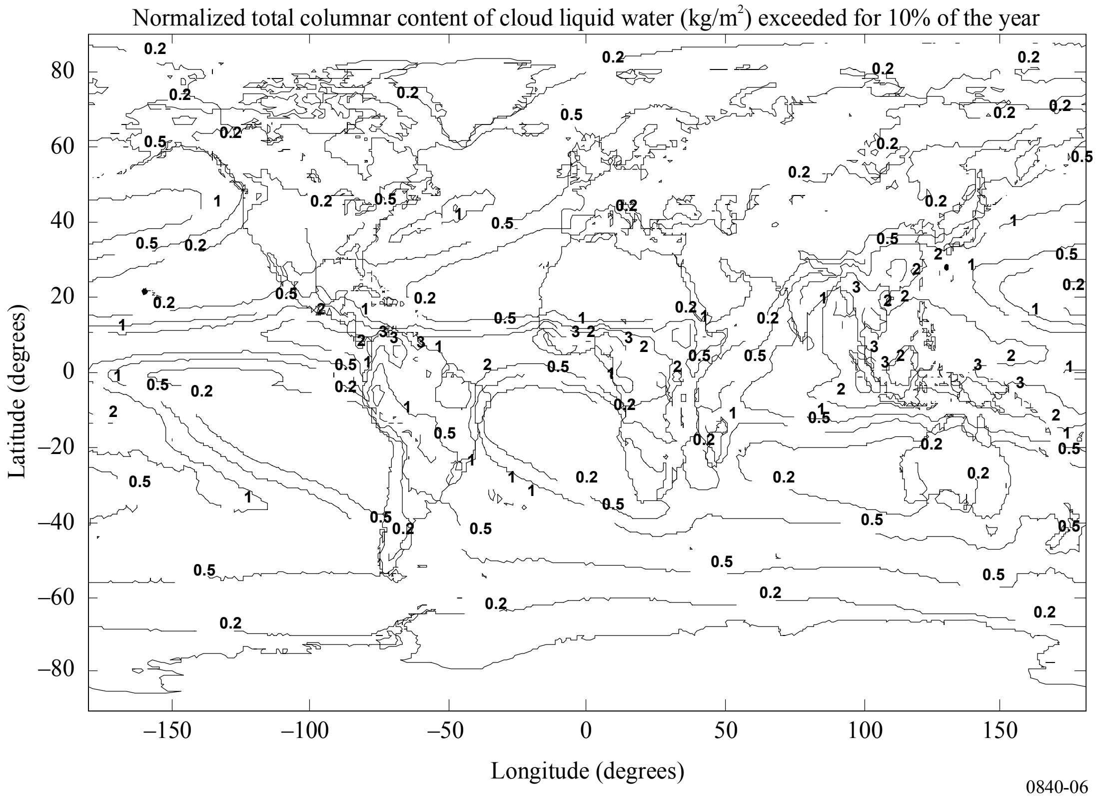

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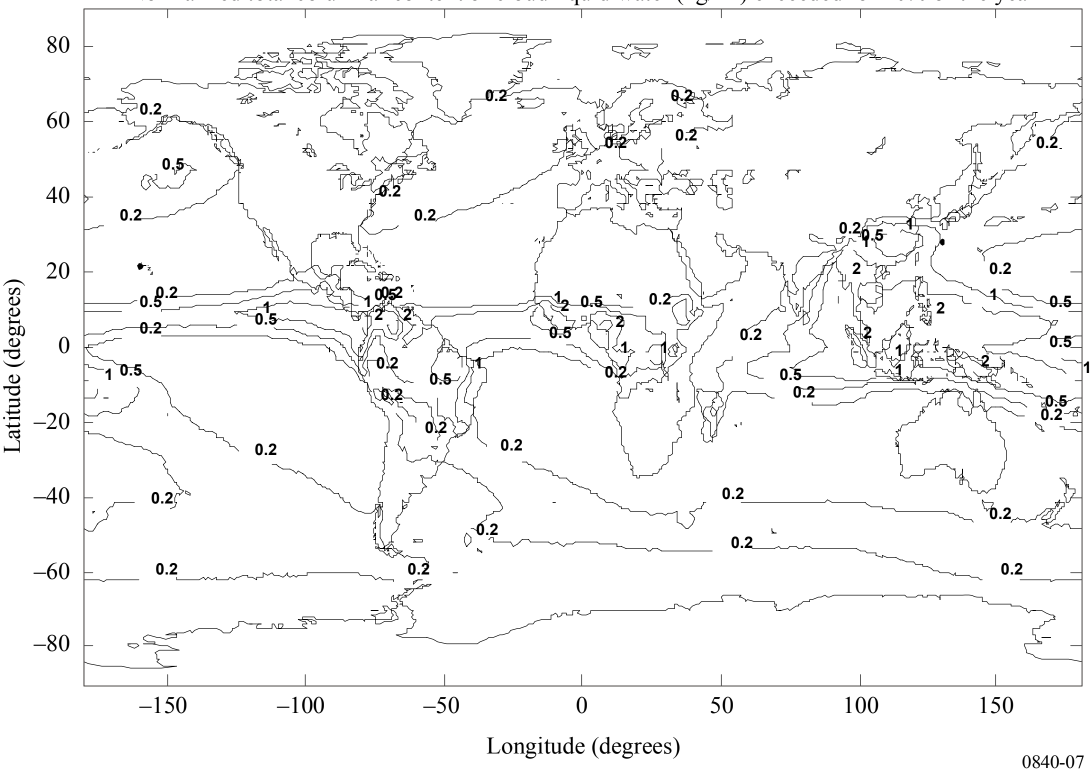
FIGURE 7

Normalized total columnar content of cloud liquid water (kg/m^2) exceeded for 20% of the year



5 Statistical distribution of total columnar content of cloud liquid water

The statistics of the total columnar content of cloud liquid water can be approximated by a log-normal distribution. The mean, m, standard deviation, σ, and probability of liquid water, P_{clw}, parameters of the log-normal distribution are available in the form of digital maps from the Radiocommunication Study Group 3 website in the data files WRED_LOGNORMAL_MEAN_v4.TXT, WRED_LOGNORMAL_STDEV_v4.TXT, and WRED_LOGNORMAL_PCLW_v4.TXT. 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. This data is to be used in conjunction with the companion data files ESALAT_1dot125.TXT and ESALON_1dot125.TXT containing the latitudes and longitudes of the corresponding entries (grid points) in data files WRED_LOGNORMAL_MEAN_v4.TXT, WRED_LOGNORMAL_STDEV_v4.TXT, and WRED_LOGNORMAL_PCLW_v4.TXT. The total columnar content of 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, $m_1, m_2, m_3, m_4, \sigma_1, \sigma_2, \sigma_3, \sigma_4, P_{CLW1}, P_{CLW2}, P_{CLW3}$ and P_{CLW4} at the four closest grid points;

b) determine the total columnar content of cloud liquid water L_1, L_2, L_3, and L_4 for the desired probability, p, at the four closest grid points from the parameters $m_1, m_2, m_3, m_4, \sigma_1, \sigma_2, \sigma_3, \sigma_4, P_{CLW1}, P_{CLW2}, P_{CLW3}$ and P_{CLW4} as follows:

$$L_i = \mathrm{e}^{m_i + \sigma_i Q^{-1}\left(\frac{P}{P_{CLWi}}\right)} \qquad \text{for } i = 1, 2, 3, 4 \tag{13}$$

where:

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_{x}^{\infty} e^{-\frac{t^2}{2}} \mathrm{d}t \qquad (14)$$

c) determine the total columnar water vapour content at the desired location by performing a bi-linear interpolation of the four values of total columnar content of cloud liquid water, L_1, L_2, L_3, and L_4 at the four grid points as described in Recommendation ITU-R P.1144.

Note that the digital maps of total columnar water vapour content contain the symbol NaN (Not-a-Number) when there is no value of total water vapour content corresponding to a given annual probability of exceedance.