

SECTION 5F: ASPECTS RELATIVE TO SPACE TELECOMMUNICATION SYSTEMS

RECOMMENDATION ITU-R PN.618-3

PROPAGATION DATA AND PREDICTION METHODS REQUIRED FOR THE DESIGN OF
EARTH-SPACE TELECOMMUNICATIONS SYSTEMS

(Question ITU-R 206/3)

(1986-1990-1992-1994)

The ITU Radiocommunication Assembly,

considering

- a) that for the proper planning of Earth-space systems it is necessary to have appropriate propagation data and prediction techniques;
- b) that methods have been developed that allow the prediction of the most important propagation parameters needed in planning Earth-space systems;
- c) that as far as possible, these methods have been tested against available data and have been shown to yield an accuracy that is both compatible with the natural variability of propagation phenomena and adequate for most present applications in system planning,

recommends

- 1. that the methods for predicting the propagation parameters set out in Annex 1 be adopted for planning Earth-space radiocommunication systems, in the respective ranges of validity indicated in the Annex.

Note 1 – Supplementary information related to the planning of broadcasting-satellite systems as well as maritime, land, and aeronautical mobile-satellite systems, may be found in Recommendations ITU-R PN.679, ITU-R PN.680, ITU-R PN.681 and ITU-R PN.682, respectively.

ANNEX 1

1. Introduction

In the design of Earth-space links for communication systems, several effects must be considered. Effects of the non-ionized atmosphere need to be considered at all frequencies, but become critical above about 1 GHz and for low elevation angles. These effects include:

- a) absorption in atmospheric gases; absorption, scattering and depolarization by hydrometeors (water and ice droplets in precipitation, clouds, etc.); and emission noise from absorbing media; all of which are especially important at frequencies above about 10 GHz;
- b) loss of signal due to beam-divergence of the earth-station antenna, due to the normal refraction in the atmosphere;
- c) a decrease in effective antenna gain, due to phase decorrelation across the antenna aperture, caused by irregularities in the refractive-index structure;
- d) relatively slow fading due to beam-bending caused by large-scale changes in refractive index; more rapid fading (scintillation) and variations in angle of arrival, due to small-scale variations in refractive index.

- e) possible limitations in bandwidth due to multiple scattering or multipath effects, especially in high-capacity digital systems;
- f) attenuation by the local environment of the ground terminal (buildings, trees, etc.);
- g) short-term variations of the ratio of attenuations at the up- and down-link frequencies, which may affect the accuracy of adaptive fade countermeasures.

This Annex deals with the propagation data required in system planning.

Effects of the Earth's ionosphere and of extra-terrestrial ionized media which may need to be considered for systems operation are treated in Recommendation ITU-R P.531 and include:

- h) rotation of the plane of polarization (Faraday rotation), particularly if frequency re-use and linear polarization are employed;
- j) dispersion, which results in a differential time delay across the bandwidth of the transmitted signal;
- k) excess time delay;
- l) scintillation, which affects amplitude, phase and angle-of-arrival of the received signal.

This Annex deals only with the effects of the troposphere on the wanted signal. Interference aspects are treated in separate Recommendations and Report:

- interference between earth stations and terrestrial stations (Recommendation ITU-R PN.452);
- interference from and to space stations (Recommendation ITU-R PN.619);
- bidirectional coordination of earth stations (Report ITU-R PN.1010).

An apparent exception is path depolarization which, although of concern only from the standpoint of interference (e.g. between orthogonally-polarized signal transmissions), is directly related to the propagation impairments of the co-polarized direct signal.

The information is arranged according to the link parameters to be considered in actual system planning, rather than according to the physical phenomena causing the different effects. As far as possible, simple prediction methods covering practical applications are provided, along with indications of their range of validity. These relatively simple methods yield satisfactory results in most practical applications, despite the large variability (from year to year and from location to location) of propagation conditions.

As far as possible, the prediction methods in this Annex have been tested against measured data from the data banks of Radiocommunication Study Group 3 (see Recommendation ITU-R PN.311).

2. Propagation loss

The propagation loss on an Earth-space path, relative to the free-space loss, is the sum of different contributions as follows:

- attenuation by atmospheric gases;
- attenuation by rain, other precipitation and clouds;
- focusing and defocusing;
- decrease in antenna gain due to wave-front incoherence;
- scintillation and multipath effects;
- attenuation by sand and dust storms.

Each of these contributions has its own characteristics as a function of frequency, geographic location and elevation angle. As a rule, at elevation angles above 10°, only gaseous attenuation, rain attenuation and possibly scintillation will exceed a few tenths of a decibel, depending on propagation conditions.

(In certain climatic zones, snow and ice accumulations on the surfaces of antenna reflectors and feeds can produce prolonged periods with severe attenuation, which might dominate even the annual cumulative distribution of attenuation.)

2.1 Attenuation due to atmospheric gases

Attenuation by atmospheric gases which is entirely caused by absorption depends mainly on frequency, elevation angle, altitude above sea level and water vapour density (absolute humidity). At frequencies below 10 GHz, it may normally be neglected. Its importance increases with frequency above 10 GHz, especially for low elevation angles. This effect is discussed in detail in Recommendation ITU-R PN.676.

2.1.1 Procedure for calculating gaseous attenuation

The method described below should be used to calculate the median gaseous absorption loss expected for a given value of surface water vapour density, ρ_w , for frequencies up to 350 GHz (excluding the 57-63 GHz band for which information may be obtained from Recommendation ITU-R PN.676).

Parameters required for the method include:

f : frequency (GHz)

θ : path elevation angle

h_s : height (km) above mean sea level of the Earth terminal; if unknown, a value of $h_s = 0$ will give somewhat conservative results

ρ_w : water vapour density (g/m^3) at the surface (i.e. at height h_s) for the location of interest.

In general, the mean or median value of ρ_w for a month or year is input to the model. Representative median values can be obtained from Recommendation ITU-R PN.836. Data are also available from some national weather services. Since the model assumes an averaged height profile for water vapour density, application of the calculation procedure to periods of less than one month may introduce inaccuracies and is not recommended.

Step 1: Calculate the specific attenuations at the surface for dry air γ_o , and water vapour, γ_w , for the frequency, f , and the water vapour density, ρ_w , as specified in Recommendation ITU-R PN.676.

Step 2: Compute the equivalent heights for dry air h_o , and water vapour, h_w , as specified in Recommendation ITU-R PN.676.

Step 3: Calculate the total slant path gaseous attenuation, A_g , through the atmosphere.

– For $\theta > 10^\circ$:

$$A_g = \frac{\gamma_o h_o e^{-h_s/h_o} + \gamma_w h_w}{\sin \theta} \quad \text{dB} \quad (1)$$

– For $\theta \leq 10^\circ$:

$$A_g = \frac{\gamma_o h_o e^{-h_s/h_o}}{g(h_o)} + \frac{\gamma_w h_w}{g(h_w)} \quad \text{dB} \quad (2)$$

with:

$$g(h) = 0.661 x + 0.339 \sqrt{x^2 + 5.5 (h/R_e)} \quad (3a)$$

$$x = \sqrt{\sin^2 \theta + 2(h_s/R_e)} \quad (3b)$$

where h is to be replaced by h_o or h_w as appropriate.

In this prediction method, R_e is the effective earth radius after accounting for refraction (see Recommendation ITU-R PN.834). Typically, a value of $R_e = 8\,500$ km is appropriate for $h_s \leq 1$ km. (For $h_s > 1$ km, see Recommendation ITU-R PN.676.)

Equations (2) to (3b) are engineering formulae derived from equations (10) to (13b) of Recommendation ITU-R PN.676, based on the following approximations:

$$\cos \theta \approx 1; \quad \sin^3 \theta \ll \sin \theta; \quad h_s^2 / R_e^2 \ll 4 h_s / R_e$$

Note that $x = \sin \theta$ for $h_s = 0$.

2.1.2 *Variability of gaseous attenuation*

At a given frequency the oxygen contribution to atmospheric absorption is relatively constant. However, both water vapour density and its vertical profile are quite variable, which makes computation of accurate cumulative statistics of gaseous attenuation difficult. Approximate distributions can be obtained from the method of § 2.1.1, if surface water vapour density statistics and concurrent surface temperature information are used. Typically, the maximum gaseous attenuation occurs during the season of maximum rainfall (see Recommendation ITU-R PN.836).

Maps illustrating the seasonal variation of absolute humidity at ground level are provided in Recommendation ITU-R PN.836. These can be used in the method to estimate the seasonal variation in clear-air attenuation.

For some systems the variations in atmospheric attenuation exceeded for large percentages of the time (when no rain is present) are important. A study of 11.4 GHz sky noise level variations at several locations in Europe showed that seasonal variations in the monthly median level of total attenuation did not exceed 0.1 dB, and that the total attenuation exceeded for 20% of the worst month was 0.05 to 0.15 dB above the monthly median value, depending on location. These attenuations are thought to be caused mainly by water vapour absorption.

2.2 *Attenuation by precipitation and clouds*

2.2.1 *Prediction of attenuation statistics for an average year*

The general method to predict attenuation due to precipitation and clouds along a slant propagation path is presented in § 2.2.1.1.

If reliable long-term statistical attenuation data are available that were measured at an elevation angle and a frequency (or frequencies) different from those for which a prediction is needed, it is often preferable to scale these data to the elevation angle and frequency in question rather than using the general method. The recommended frequency-scaling method is found in § 2.2.1.2.

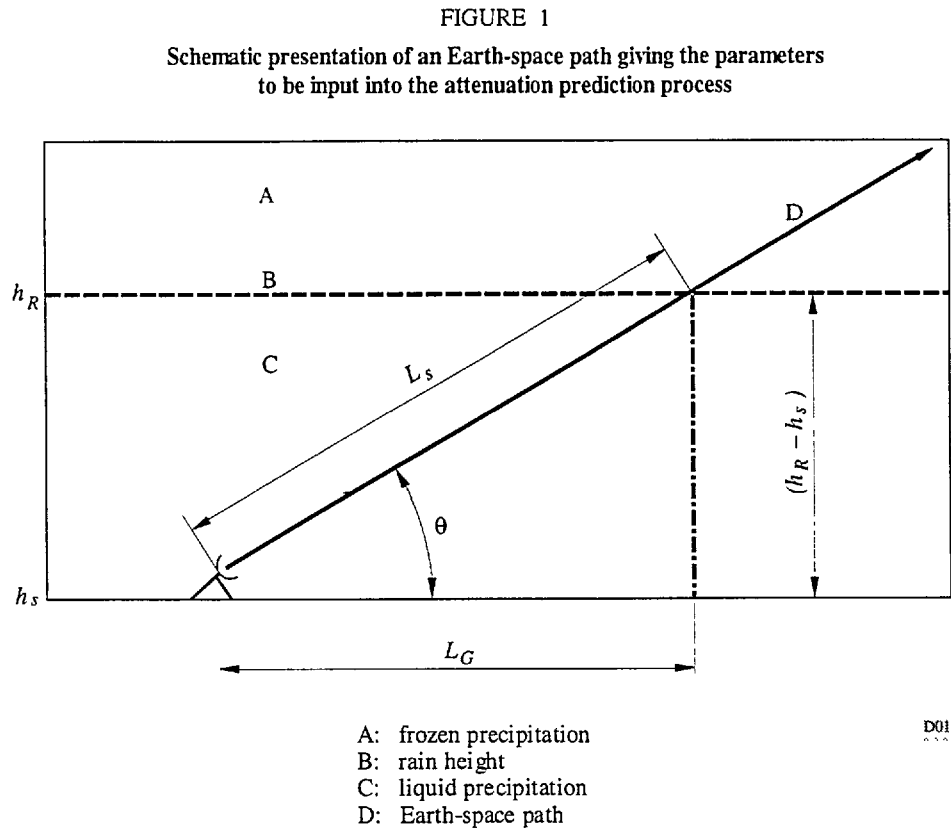
Site diversity effects may be estimated with the method of § 2.2.4.

2.2.1.1 *Calculation of long-term rain attenuation statistics from point rainfall rate*

The following procedure provides estimates of the long-term statistics of the slant-path rain attenuation at a given location for frequencies up to 30 GHz. The following parameters are required:

- $R_{0.01}$: point rainfall rate for the location for 0.01% of an average year (mm/h)
- h_s : height above mean sea level of the earth station (km)
- θ : elevation angle
- ϕ : absolute value of latitude of the earth station (degrees)
- f : frequency (GHz).

The geometry is illustrated in Fig. 1.



D01

Step 1: Calculate the effective rain height, h_R , for the latitude of the station φ :

$$h_R \text{ (km)} = \begin{cases} 3.0 + 0.028 \varphi & \text{for } 0 \leq \varphi < 36^\circ \\ 4.0 - 0.075 (\varphi - 36) & \text{for } \varphi \geq 36^\circ \end{cases} \quad (4)$$

Step 2: For $\theta \geq 5^\circ$ compute the slant-path length, L_s , below the rain height from:

$$L_s = \frac{(h_R - h_s)}{\sin \theta} \quad \text{km} \quad (5)$$

For $\theta < 5^\circ$, the following formula is used:

$$L_s = \frac{2(h_R - h_s)}{\left(\sin^2 \theta + \frac{2(h_R - h_s)}{R_e} \right)^{1/2} + \sin \theta} \quad \text{km} \quad (6)$$

Step 3: Calculate the horizontal projection, L_G , of the slant-path length from:

$$L_G = L_s \cos \theta \quad \text{km} \quad (7)$$