International Telecommunication Union

# ITU-R
## Radiocommunication Sector of ITU

Recommendation **ITU-R P.617-3**
(09/2013)

# Propagation prediction techniques and data required for the design of trans-horizon radio-relay systems

**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.

## 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 Annex 1 of 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.

<table>
<tr><td colspan="2" align="center">**Series of ITU-R Recommendations**<br>(Also available online at http://www.itu.int/publ/R-REC/en)</td></tr>
<tr><td>**Series**</td><td align="center">**Title**</td></tr>
<tr><td>**BO**</td><td>Satellite delivery</td></tr>
<tr><td>**BR**</td><td>Recording for production, archival and play-out; film for television</td></tr>
<tr><td>**BS**</td><td>Broadcasting service (sound)</td></tr>
<tr><td>**BT**</td><td>Broadcasting service (television)</td></tr>
<tr><td>**F**</td><td>Fixed service</td></tr>
<tr><td>**M**</td><td>Mobile, radiodetermination, amateur and related satellite services</td></tr>
<tr><td>**P**</td><td>**Radiowave propagation**</td></tr>
<tr><td>**RA**</td><td>Radio astronomy</td></tr>
<tr><td>**RS**</td><td>Remote sensing systems</td></tr>
<tr><td>**S**</td><td>Fixed-satellite service</td></tr>
<tr><td>**SA**</td><td>Space applications and meteorology</td></tr>
<tr><td>**SF**</td><td>Frequency sharing and coordination between fixed-satellite and fixed service systems</td></tr>
<tr><td>**SM**</td><td>Spectrum management</td></tr>
<tr><td>**SNG**</td><td>Satellite news gathering</td></tr>
<tr><td>**TF**</td><td>Time signals and frequency standards emissions</td></tr>
<tr><td>**V**</td><td>Vocabulary and related subjects</td></tr>
</table>

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

*Electronic Publication*
Geneva, 2013

RECOMMENDATION ITU-R P.617-3*

# Propagation prediction techniques and data required for the design of trans-horizon radio-relay systems

(Question ITU-R 205/3)

(1986-1992-2012-2013)

The ITU Radiocommunication Assembly,

*considering*

a)      that for the proper planning of trans-horizon radio-relay systems it is necessary to have appropriate propagation prediction methods and data;

b)      that methods have been developed that allow the prediction of most of the important propagation parameters affecting the planning of trans-horizon radio-relay systems;

c)      that as far as possible these methods have been tested against available measured 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*

that the prediction methods and other techniques set out in Annex 1 be adopted for planning trans-horizon radio-relay systems in the respective ranges of parameters indicated.

# Annex 1

## 1      Introduction

The only mechanisms for radio propagation beyond the horizon which occur permanently for frequencies greater than 30 MHz are those of diffraction at the Earth's surface and scatter from atmospheric irregularities. Attenuation for diffracted signals increases very rapidly with distance and with frequency, and eventually the principal mechanism is that of tropospheric scatter. Both mechanisms may be used to establish "trans-horizon" radiocommunication. Because of the dissimilarity of the two mechanisms it is necessary to consider diffraction and tropospheric scatter paths separately for the purposes of predicting transmission loss.

This Annex relates to the design of trans-horizon radio-relay systems. One purpose is to present in concise form simple methods for predicting the annual and worst-month distributions of transmission loss due to tropospheric scatter, together with information on their ranges of validity. Another purpose of this Annex is to present other information and techniques that can be recommended in the planning of trans-horizon systems.

---

\*      Radiocommunication Study Group 3 made editorial amendments to this Recommendation in April 2015 in accordance with Resolution ITU-R 1.

## 2        Integral digital products

The file TropoClim.txt is an ASCII file that provides the identification of the different climatic zones in terms of an integer value and is available in the file R-REC-P.617-3-201309-I!!ZIP-E. The data is represented as gridded latitude/longitude values in the "standard" ITU-R format. The data format is defined as:

TABLE 1

| Source | Latitude (rows) | | | Longitude (columns) | | |
|--------|-----------------|---|---|---------------------|---|---|
|        | First row (°N) | Spacing (degrees) | Number of rows | First col (°E) | Spacing (degrees) | Number of cols |
| P.2001 | 89.75 | 0.5 | 360 | −179.75 | 0.5 | 720 |

NOTE 1 – The "First row" value is the latitude of the first row.

NOTE 2 – The "First col" value is the longitude of the first column. The columns represent longitudes increasing from 179.75°W to 179.75°E inclusive. That is, the longitude increases eastward.

NOTE 3 – "Spacing" gives the latitude/longitude increment between rows/columns.

NOTE 4 – The file TropoClim.txt contains integer zone identifiers rather than continuous meteorological variables. Consequently, the values should **not** be interpolated to obtain a value at a particular latitude/longitude. Instead the value at the closest gridpoint should be taken. For this file note that the value in the last column is not a duplicate of the first column. Consequently the latitudes of the rows range from 89.75°N to 89.75°S, and the longitudes of the columns range from 179.75°W to 179.75°E.

## 3        Transmission loss for diffraction paths

For radio paths extending only slightly over the horizon, or for paths extending over an obstacle or over mountainous terrain, diffraction will generally be the propagation mode determining the field strength. In these cases, the methods described in Recommendation ITU-R P.526 should be applied.

## 4        Transmission loss distribution on tropospheric scatter paths

Signals received by means of tropospheric scatter show both slow and rapid variations. The slow variations are due to overall changes in refractive conditions in the atmosphere and the rapid fading to the motion of small-scale irregularities. The slow variations are well described by distributions of the hourly-median transmission loss which are approximately log-normal with standard deviations between about 4 and 8 dB, depending on climate. The rapid variations over periods up to about 5 min are approximately Rayleigh distributed.

In determining the performance of trans-horizon links for geometries in which the tropospheric scatter mechanism is predominant, it is normal to estimate the distribution of hourly-median transmission loss for non-exceedance percentages of the time above 50%. A simple semi-analytical technique for predicting the distribution of average annual transmission loss in this range is given in § 4.1. A graphical technique for translating these annual time percentages to those for the average worst month is given in § 4.2. Finally, guidance is given in § 4.3 on estimation of the transmission loss distribution for small percentages of time for use in obtaining receiver dynamic ranges required. Appendix 1 includes additional supporting information on seasonal and diurnal variations in transmission loss, on frequency of rapid fading on tropospheric scatter paths and on transmission bandwidth.

### 4.1 Average annual median transmission loss distribution for time percentages greater than 50%

The following step-by-step procedure is recommended for estimating the average annual median transmission loss $L(q)$ not exceeded for percentages of the time $q$ greater than 50%. The procedure requires the link parameters of great-circle path length $d$ (km), frequency $f$ (MHz), transmitting antenna gain $G_t$ (dB), receiving antenna gain $G_r$ (dB), horizon angle $\theta_t$ (mrad) at the transmitter, and horizon angle $\theta_r$ (mrad) at the receiver:

*Step 1:* Determine the appropriate climate for the common volume of the link in question using the climate map of Fig. 1. This map, TropoClim.txt, is an integral digital part to this Recommendation (see § 2).

FIGURE 1

**Climate zone classification**
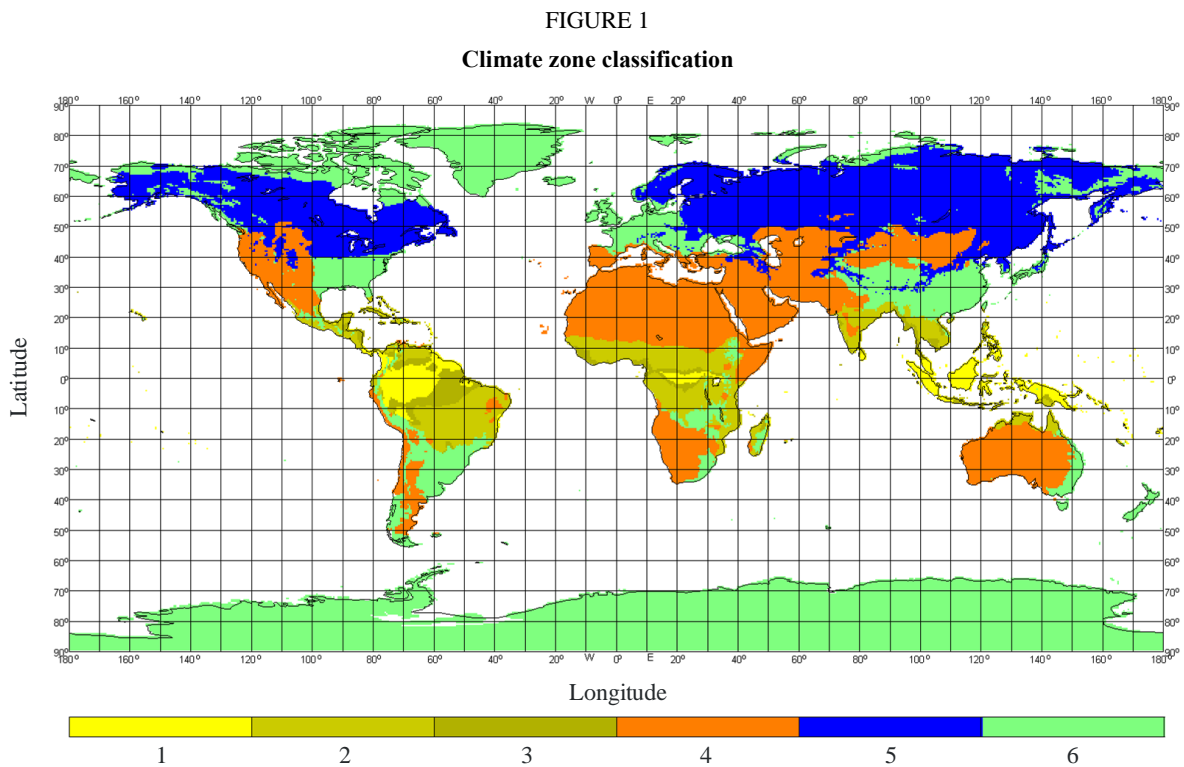


P.0617-01

If the troposcatter common volume lies over the sea, the climates at both the transmitter and receiver locations are determined. If both terminals have a climate zone corresponding to a land point, the climate zone of the path is given by the smaller value of the transmitter and receiver climate zones. If only one terminal has a climate zone corresponding to a land point, then that climate zone defines the climate zone of the path. If neither terminal has a climate zone corresponding to a land point, the path is assigned a "sea path" climate zone.

*Step 2:* Obtain the meteorological and atmospheric structure parameters $M$ and $\gamma$, respectively, and the equation to be used for calculating $Y(90)$ from Table 2 for the climate in question.

TABLE 2

**Values of meteorological and atmospheric structure parameters**

| Climate | 1 | 2 | 3 | 4 | 5 | 6 | Sea* |
|---------|------|------|------|------|------|------|------|
| $M$ (dB) | 39.60 | 29.73 | 19.30 | 38.50 | 29.73 | 33.20 | 26.00 |
| $\gamma$ (km$^{-1}$) | 0.33 | 0.27 | 0.32 | 0.27 | 0.27 | 0.27 | 0.27 |
| $Y(90)$ *Equation* | 9 | 7 | 10 | 11 | 7 | 7 | 8 |

     * Sea is coded as 0 in the TropoClim.txt

*Step 3:* Calculate the scatter angle θ (angular distance) from:

$$\theta = \theta_e + \theta_t + \theta_r \qquad \text{mrad} \qquad (1)$$

where $\theta_t$ and $\theta_r$ are the transmitter and receiver horizon angles, respectively, and

$$\theta_e = d \cdot 10^3 / ka \qquad \text{mrad} \qquad (2)$$

with:

    $d$ :    path length (km)

    $a$ :    6 370 km radius of the Earth

    $k$ :    effective earth radius factor for median refractivity conditions ($k$ = 4/3 should be used unless a more accurate value is known)

*Step 4:* Estimate the transmission loss dependence $L_N$ on the height of the common volume from:

$$L_N = 20 \log(5 + \gamma H) + 4.34 \gamma h \qquad \text{dB} \qquad (3)$$

where:

$$H = 10^{-3} \theta d / 4 \qquad \text{km} \qquad (4)$$

$$h = 10^{-6} \theta^2 k a / 8 \qquad \text{km} \qquad (5)$$

and γ is the atmospheric structure parameter obtained in Step 2.

*Step 5:* Estimate the conversion factor $Y(q)$ for non-exceedance percentages $q$ other than 50% from:

$$Y(q) = C(q) Y(90) \qquad \text{dB} \qquad (6)$$

Here $Y(90)$ is the conversion factor for $q$ = 90% given by the appropriate equation (7-11) as indicated in Table 2 for the climate in question:

$$Y_{90} = -2.2 - \left[8.1 - 2.3 \cdot 10^{-4} \min(f, 4000)\right] \exp(-0.137h) \qquad (7)$$

$$Y_{90} = -9.5 - 3\exp(-0.137h) \qquad (8)$$

$$Y_{90} = -8.2 \qquad\qquad d_s < 100 \qquad\qquad (9a)$$

$$Y_{90} = 1.006 \cdot 10^{-8} d_s^3 - 2.569 \cdot 10^{-5} d_s^2 + 0.02242 d_s - 10.2 \qquad 100 \leq d_s < 1000 \qquad (9b)$$

$$Y_{90} = -3.4 \qquad\qquad \text{otherwise} \qquad\qquad (9c)$$

$$Y_{90} = -10.845 \qquad\qquad d_s < 100 \qquad\qquad (10a)$$

$$Y_{90} = -4.5 \cdot 10^{-7} d_s^3 + 4.45 \cdot 10^{-4} d_s^2 - 0.122 d_s - 2.645 \qquad 100 \leq d_s < 465 \qquad (10b)$$

$$Y_{90} = -8.4 \qquad\qquad \text{otherwise} \qquad\qquad (10c)$$

$$Y_{90} = -11.5 \qquad\qquad d_s < 100 \qquad\qquad (11a)$$

$$Y_{90} = -8.519 \cdot 10^{-8} d_s^3 + 7.444 \cdot 10^{-5} d_s^2 - 4.18 \cdot 10^{-4} d_s - 12.1 \qquad 100 \leq d_s < 550 \qquad (11b)$$

$$Y_{90} = -4 \qquad\qquad \text{otherwise} \qquad\qquad (11c)$$

where:

$$d_s = \theta_{ka}/1000 \qquad\qquad \text{km} \qquad\qquad (12)$$

The coefficient $C(q)$ for the non-exceedance percentage of time $q$ in question can be obtained from Table 3.

TABLE 3

**Values of $C(q)$ of interest**

| $q$ | 50 | 90 | 99 | 99.9 | 99.99 |
|---|---|---|---|---|---|
| $C(q)$ | 0 | 1 | 1.82 | 2.41 | 2.90 |

*Step 6:* Estimate the aperture-to-medium coupling loss $L_c$ from:

$$L_c = 0.07 \ \exp\left[0.055(G_t + G_r)\right] \qquad\qquad \text{dB} \qquad (13)$$

where $G_t$ and $G_r$ are the antenna gains.

*Step 7:* Estimate the average annual transmission loss not exceeded for $q$% of the time from:

$$L(q) = M + 30 \log f + 10 \log d + 30 \log \theta + L_N + L_c - G_t - G_r - Y(q) \qquad\qquad \text{dB} \quad (14)$$

NOTE 1 – Equation (14) is an empirical formula based on data for the frequency range between 200 MHz and 4 GHz. It can be extended to 5 GHz with little error for most applications.

## 4.2 Average worst-month median transmission loss distribution for time percentages greater than 50%

For reasons of consistency with the average annual transmission loss distribution, this distribution is best determined from the average annual distribution by means of a conversion factor. The procedure is as follows:

*Step 1:* Obtain the average annual distribution for the non-exceedance percentages (50, 90, 99, 99.9) and climate(s) of interest using the technique in § 4.1.

*Step 2:* Obtain the basic transmission loss difference between the average annual distribution and the average worst-month distribution from the curves of Fig. 2. Since owing to lack of measurement data curves are not available for climates 2 or 5, the curves for climate 3 should be used for climate 2 and the curves for climate 6 should be used for climate 5.

The equivalent distance used in Fig. 2 is defined as:

$$d_q = d + 8.5(\theta_t + \theta_r) \qquad \text{km} \qquad (15)$$

Where the symbols have the same value as evaluated in § 4.1.

*Step 3:* Add the difference in Step 2 to the corresponding average annual values obtained in Step 1 to obtain the average worst-month transmission losses for the non-exceedance percentages (50, 90, 99, 99.9).

*Step 4:* Average worst-month transmission losses not exceeded for 99.99% of the time can be estimated from the values above by logarithmic extrapolation (i.e. extrapolating from a plot on normal probability paper).

## 4.3 Average annual median transmission loss distribution for time percentages less than 50%

For percentages of time between about 20% (as low as 1% in some dry climates over land) and 50%, the average annual transmission loss distribution can be considered symmetrical and the transmission loss values estimated from the corresponding values above the median, i.e.

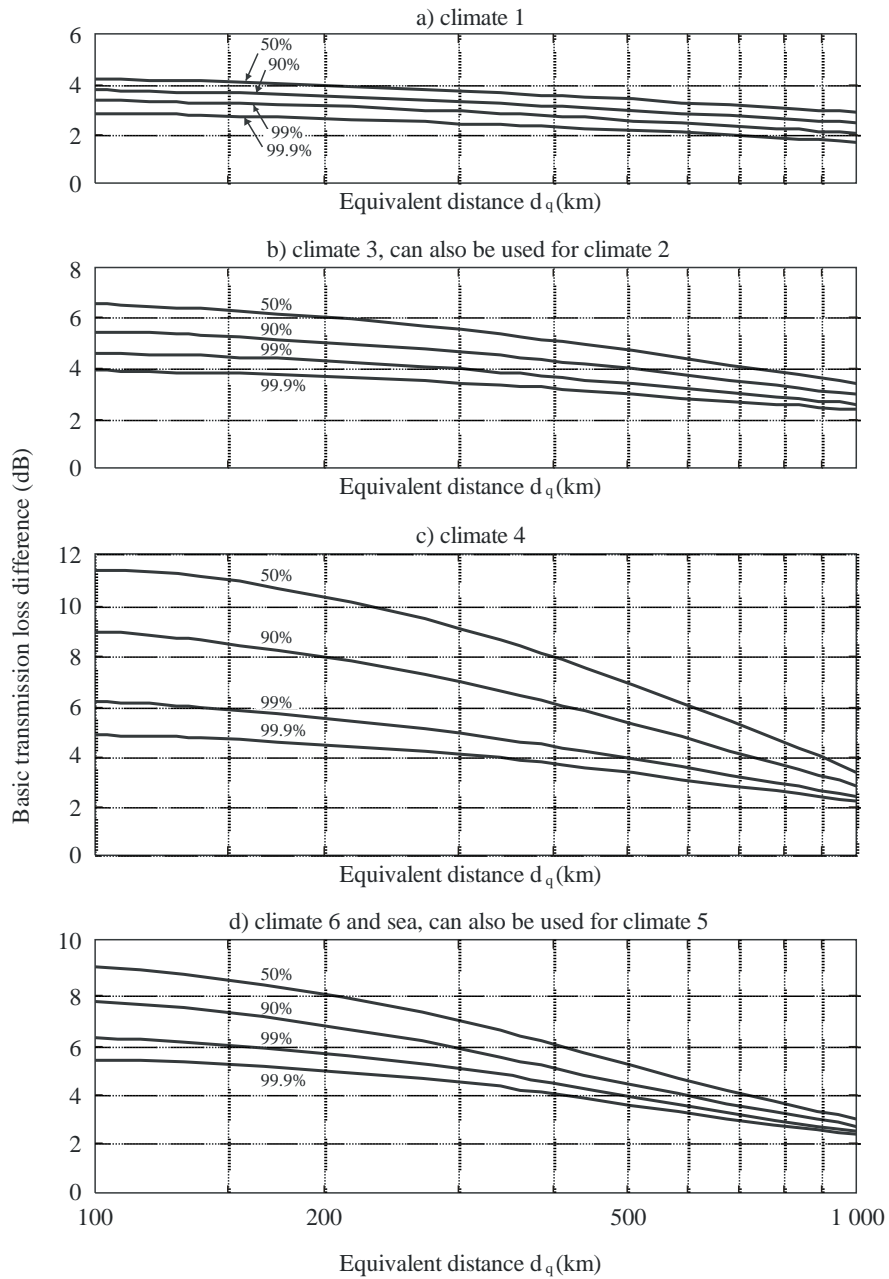$$L(20\%) = L(50\%) - [L(80\%) - L(50\%)] \qquad (16)$$

However, for dynamic range calculations requiring estimates of the distribution for lower time percentages, pure tropospheric scatter cannot be assumed. The transmission loss values not exceeded for very small percentages of time will be determined by the duct propagation mechanism. These values are best estimated by the technique given in Recommendation ITU-R P.452.

## 5 Diversity reception

The deep fading occurring with tropospheric scatter propagation severely reduces the performance of systems using this propagation mode. The effect of the fading can be reduced by diversity reception, using two or more signals which fade more or less independently owing to differences in scatter path or frequency. Thus, the use of space, angle, or frequency diversity is known to decrease the percentages of time for which large transmission losses are exceeded. Angle diversity, however, can have the same effect as vertical space diversity and be more economical.

FIGURE 2

**Curves giving the difference between worst-month basic transmission loss and annual basic transmission loss**

a) climate 1

b) climate 3, can also be used for climate 2

c) climate 4

d) climate 6 and sea, can also be used for climate 5

Equivalent distance $d_q$ (km)

P.0617-02

## 5.1 Space diversity

Diversity spacing in the horizontal or vertical can be used depending on whatever is most convenient for the location in question. Adequate diversity spacings $\Delta h$ and $\Delta v$ in either the horizontal or vertical, respectively, for frequencies greater than 1 000 MHz are given by the empirical relations:

$$\Delta h = 0.36 \left(D^2 + 4I_h^2\right)^{1/2} \qquad \text{m} \qquad (17)$$

$$\Delta v = 0.36 \left(D^2 + 4I_v^2\right)^{1/2} \qquad \text{m} \qquad (18)$$

where $D$ is the antenna diameter in metres and $I_h = 20$ m and $I_v = 15$ m are empirical scale lengths in the horizontal and vertical directions, respectively.

## 5.2 Frequency diversity

For installations where it is desired to employ frequency diversity, an adequate frequency separation $\Delta f$ (MHz) is given for frequencies greater than about 1 000 MHz by the relation:

$$\Delta f = \left(1.44 f / \theta d\right) \left(D^2 + I_v^2\right)^{1/2} \qquad \text{MHz} \qquad (19)$$

where:

$\quad\quad\quad f$ : frequency (MHz)

$\quad\quad\quad D$ : antenna diameter (m)

$\quad\quad\quad \theta$ : scatter angle (mrad) obtained from equation (1)

$\quad\quad\quad I_v$ : 15 m the scale length noted above.

## 5.3 Angle diversity

Vertical angle diversity can also be used in which two or more antenna feeds spaced in the vertical direction are employed with a common reflector. This creates different vertically-spaced common volumes similar to the situation for vertical space diversity. The angular spacing $\Delta\theta_r$ required to have approximately the same effect as the vertical spacing $\Delta v$ (m) in equation (18) on an approximately symmetrical path is:

$$\Delta\theta_r = \text{arc tan} \left(\Delta v / 500d\right) \qquad (20)$$

where $d$ is the path length (km).

## 6 Effect of the siting of stations

The siting of transmission links requires some care. The antenna beams must not be obstructed by nearby objects and the antennas should be directed slightly above the horizon. The precise optimum elevation is a function of the path and atmospheric conditions, but it lies within about 0.2 to 0.6 beamwidths above the horizon.

Measurements made by moving the beam of a 53 dB gain antenna away from the great-circle horizon direction of two 2 GHz transmitters, each 300 km distant, demonstrated an apparent rate-of-decrease of power received of 9 dB per degree. This occurred with increases of scattering angle over the first three degrees, in both azimuth and elevation, for each path, and for a wide range of time percentages.

# Appendix 1

# Additional supporting material

## 1 Seasonal and diurnal variations in transmission loss

In temperate climates, transmission loss varies annually and diurnally. Monthly median losses tend to be higher in winter than in summer. The range is 10 to 15 dB on 150-250 km overland paths but diminishes as the distance increases. Measurements made in the European parts of the Russian Federation on a 920 km path at 800 MHz show a difference of only 2 dB between summer and winter medians. Diurnal variations are most pronounced in summer, with a range of 5 to 10 dB on 100-200 km overland paths. The greatest transmission loss occurs in the afternoon, and the least in early morning. Oversea paths are more likely to be affected by super-refraction and elevated layers than land paths, and so give greater variation. This may also apply to low, flat coastal regions in maritime zones.

In dry, hot desert climates attenuation reaches a maximum in the summer. The annual variations of the monthly medians for medium-distance paths exceed 20 dB, while the diurnal variations are very large.

In equatorial climates, the annual and diurnal variations are generally small.

In monsoon climates where measurements have been carried out (Senegal, Barbados), the maximum values of $N_s$ occur during the wet season, but the minimum attenuation is between the wet and dry seasons.

## 2 Frequency of rapid fading on tropospheric scatter paths

The rapid fading has a frequency of a few fades per minute at lower frequencies and a few hertz at UHF. The superposition of a number of variable incoherent components would give a signal whose amplitude was Rayleigh distributed and this is found to be nearly true when the distribution is analysed over periods of up to 5 min. If other types of signal form a significant part of that received, there is a modification of this distribution. Sudden, deep and rapid fading has been noted when a frontal disturbance passes over a link. Reflections from aircraft can give pronounced rapid fading.

The frequency of the rapid fading has been studied in terms of the time autocorrelation function, which provides a "mean fading frequency" for short periods of time for which the signal is stationary. The median value of the mean fading frequency was found to increase nearly proportionally to path length and carrier frequency, and to decrease slightly with increasing antenna diameter.

Measurements have also shown that the rapidity of fading is greatest when the hourly median transmission loss is greater than the long-term median. In general, it was found that the fading rate decreased with decreasing transmission loss below the long-term median, the lowest fading rates occurring for events in which duct propagation was predominant.

It is the most rapid fading for hourly-median transmission loss values larger than the long-term median that is most important, and the few measurements available (at 2 GHz) give median fading rates between about 20 and 30 fades/min.

## 3        Transmissible bandwidth

The various discontinuities which give rise to scatter propagation, create propagation paths which may vary in number and in transmission time. Accordingly, the transmission coefficients for two adjacent frequencies are not entirely correlated, which leads to a distortion of the transmitted signal. The transmissible bandwidth is the bandwidth within which the distortion caused by this phenomenon is acceptable for the transmitted signal. This bandwidth therefore depends both on the nature of the transmitted signal (multiplex telephony, television picture, etc.) and on the acceptable distortion for this signal. Studies carried out in France show that:

–        increasing the antenna gain widens the transmissible bandwidth to the extent where the gain degradation increases also (i.e. for gains exceeding approximately 30 dB);

–        all other things being equal, the transmissible bandwidth depends on the atmospheric structure and hence on the climatic zone in question;

–        the transmissible bandwidth becomes narrower as the distance increases, but this is governed by a law which is not the same for all climates;

–        the transmissible bandwidth becomes narrower when there are positive angles of departure, and wider when these angles are negative.