

## RECOMMENDATION ITU-R P.1546-3

**Method for point-to-area predictions for terrestrial services in the frequency range 30 MHz to 3 000 MHz**

(2001-2003-2005-2007)

**Scope**

This Recommendation describes a method for point-to-area radio propagation predictions for terrestrial services in the frequency range 30 MHz to 3 000 MHz. It is intended for use on tropospheric radio circuits over land paths, sea paths and/or mixed land-sea paths between 1-1 000 km length for effective transmitting antenna heights less than 3 000 m. The method is based on interpolation/extrapolation from empirically derived field-strength curves as functions of distance, antenna height, frequency and percentage time. The calculation procedure also includes corrections to the results obtained from this interpolation/extrapolation to account for terrain clearance and terminal clutter obstructions.

The ITU Radiocommunication Assembly,

*considering*

- a) that there is a need to give guidance to engineers in the planning of terrestrial radiocommunication services in the VHF and UHF bands;
- b) that, for stations working in the same or adjacent frequency channels, the determination of the minimum geographical distance of separation required to avoid unacceptable interference due to long-distance tropospheric propagation is a matter of great importance;
- c) that the curves that appear in Annexes 2, 3 and 4 are based on the statistical analysis of experimental data,

*noting*

- a) that Recommendation ITU-R P.528 provides guidance on the prediction of point-to-area path loss for the aeronautical mobile service for the frequency range 125 MHz to 30 GHz and the distance range up to 1 800 km;
- b) that Recommendation ITU-R P.452 provides guidance on the detailed evaluation of microwave interference between stations on the surface of the Earth at frequencies above about 0.7 GHz;
- c) that Recommendation ITU-R P.617 provides guidance on the prediction of point-to-point (P-P) path loss for trans-horizon radio-relay systems for the frequency range above 30 MHz and for the distance range 100 to 1 000 km;
- d) that Recommendation ITU-R P.1411 provides guidance on prediction for short-range (up to 1 km) outdoor services;
- e) that Recommendation ITU-R P.530 provides guidance on the prediction of P-P path loss for terrestrial line-of-sight systems,

*recommends*

**1** that the procedures given in Annexes 1 to 8 should be used for point-to-area prediction of field strength for the broadcasting, land mobile, maritime mobile and certain fixed services (e.g. those employing point-to-multipoint (P-MP) systems) in the frequency range 30 MHz to 3 000 MHz and for the distance range 1 km to 1 000 km.

## **Annex 1**

### **Introduction**

#### **1 The propagation curves**

The propagation curves in Annexes 2, 3 and 4 represent field-strength values for 1 kW effective radiated power (e.r.p.) at nominal frequencies of 100, 600 and 2 000 MHz, respectively, as a function of various parameters; some curves refer to land paths, others refer to sea paths. Interpolation or extrapolation of the values obtained for these nominal frequency values should be used to obtain field-strength values for any given required frequency using the method given in Annex 5, § 6.

The curves are based on measurement data mainly relating to mean climatic conditions in temperate regions containing cold and warm seas, e.g. the North Sea and the Mediterranean Sea. The land-path curves were prepared from data obtained mainly from temperate climates as encountered in Europe and North America. The sea-path curves were prepared from data obtained mainly from the Mediterranean and the North Sea regions. Extensive studies reveal that propagation conditions in certain areas of super-refractivity bounded by hot seas are substantially different.

However, the methods for interpolation and extrapolation between the families of field-strength curves are general. Therefore, if families of curves exist for regions with different climates which experience substantially different prevailing radio propagation conditions, accurate characterization of radio propagation in these regions may be attained using the methods found in this Recommendation.

This Recommendation is not specific to a particular polarization.

#### **2 Maximum field strengths**

The curves have upper limits on the possible value of field strength which may be obtained under any conditions. These limits are defined in Annex 5, § 2 and appear as dashed lines on the graphs reproduced in Annexes 2, 3, and 4.

#### **3 Computer-based tabulations**

Although field strengths may be read directly from the curves presented as figures in Annexes 2, 3 and 4 of this Recommendation, it is intended that computer implementations of the method will use tabulated field strengths available from the Radiocommunication Bureau. See that part of the ITU-R website dealing with Radiocommunication Study Group 3.

#### **4 Step-by-step method**

The detailed step-by-step procedure to be used in the application of this Recommendation is given in Annex 6.

#### **5 Designation of antennas**

In this Recommendation, the term “transmitting/base antenna” is used to deal with both the concept of transmitting antenna as used in the broadcasting service and the concept of base station antenna as used in the terrestrial mobile services. Similarly, the term “receiving/mobile antenna” is used to deal with the concept of a receiving antenna as used in the broadcasting service and a mobile antenna as used in the terrestrial mobile services. More information on the designation of the terminals can be found in Annex 5, § 1.1.

#### **6 Transmitting/base antenna height**

The method takes account of the effective height of the transmitting/base antenna, which is the height of the antenna above terrain height averaged between distances of 3 to 15 km in the direction of the receiving/mobile antenna. For land paths shorter than 15 km where the information is available the method also takes account of the height of the transmitting/base antenna above the height of representative clutter (i.e. ground cover) at the location of the transmitting/base station. The transmitting/base antenna height,  $h_1$ , to be used for calculations is obtained using the method given in Annex 5, § 3.

#### **7 Transmitting/base antenna heights used for curves**

The field strength versus distance curves in Annexes 2, 3 and 4, and the associated tabulations, are given for values of  $h_1$  of 10, 20, 37.5, 75, 150, 300, 600 and 1 200 m. For any values of  $h_1$  in the range 10 m to 3 000 m an interpolation or extrapolation from the appropriate two curves should be used, as described in Annex 5, § 4.1. For  $h_1$  below 10 m, the extrapolation to be applied is given in Annex 5, § 4.2. It is possible for the value of  $h_1$  to be negative, in which case the method given in Annex 5, § 4.3 should be used.

#### **8 Time variability**

The propagation curves represent the field-strength values exceeded for 50%, 10% and 1% of time. A method for interpolating between these values is given in Annex 5, § 7. This Recommendation is not valid for field strengths exceeded for percentage times outside the range from 1% to 50%.

#### **9 Mixed-path method**

In cases where the radio path is over both land and sea the estimate of mixed-path field strength should be made using the method given in Annex 5, § 8.

#### **10 Receiving/mobile antenna height**

For land paths the curves give field-strength values for a receiving/mobile antenna height above ground,  $h_2$  (m), equal to the representative height of ground cover around the receiving/mobile antenna location. The minimum value of the representative height of ground cover is 10 m. For sea paths the curves give field-strength values for  $h_2 = 10$  m. To allow for values of  $h_2$  different from

the height represented by a curve a correction should be applied according to the environment of the receiving/mobile antenna. The method for calculating this correction is given in Annex 5, § 9.

### **11 Terrain clearance angle correction**

For land paths, improved accuracy of predicted field strengths can be obtained by taking into account terrain near the receiving/mobile antenna, if available, by means of a terrain clearance angle. When a calculation for a mixed path has been made, this correction should be included if the receiving/mobile antenna is adjacent to a land section of the path. More information on the terrain clearance angle correction is given in Annex 5, § 11.

### **12 Location variability**

The propagation curves represent the field-strength values exceeded at 50% of locations within any area of typically 500 m by 500 m. For more information on location variability and the method for calculating the correction required for percentages of location other than 50%, see Annex 5, § 12.

### **13 Equivalent basic transmission loss**

Annex 5, § 14 gives a method for converting from field strength for 1 kW e.r.p. to the equivalent basic transmission loss.

### **14 Variability of atmospheric refractive index**

It is known that median field strength and its variability over time varies in different climatic regions. The field strength curves given in Annexes 2, 3 and 4 apply to temperate climates. Annex 8 gives a method of adjusting the curves for different regions of the world based on the vertical atmospheric refractivity gradient data associated with Recommendation ITU-R P.453.

### **15 Compatibility with the Okumura-Hata method**

Annex 7 gives the Hata equations for field strength prediction for mobile services in an urban environment, and describes the conditions under which this Recommendation gives compatible results.

## **Annex 2**

### **Frequency range 30 MHz to 300 MHz**

**1** The field strength versus distance curves shown in this Annex are for a frequency of 100 MHz. They may be used for frequencies in the range 30 MHz to 300 MHz but the procedure given in Annex 5, § 6 should be used to obtain improved accuracy. The same procedure should be used when the tabulated values of field strength versus distance (see Annex 1, § 3) are employed.

**2** The curves in Figs. 1 to 3 represent field-strength values exceeded at 50% of the locations within any area of approximately 500 m by 500 m and for 50%, 10% and 1% of the time for land paths.

**3** The field strength distribution as a function of percentage location may be calculated using the information in Annex 5, § 12.

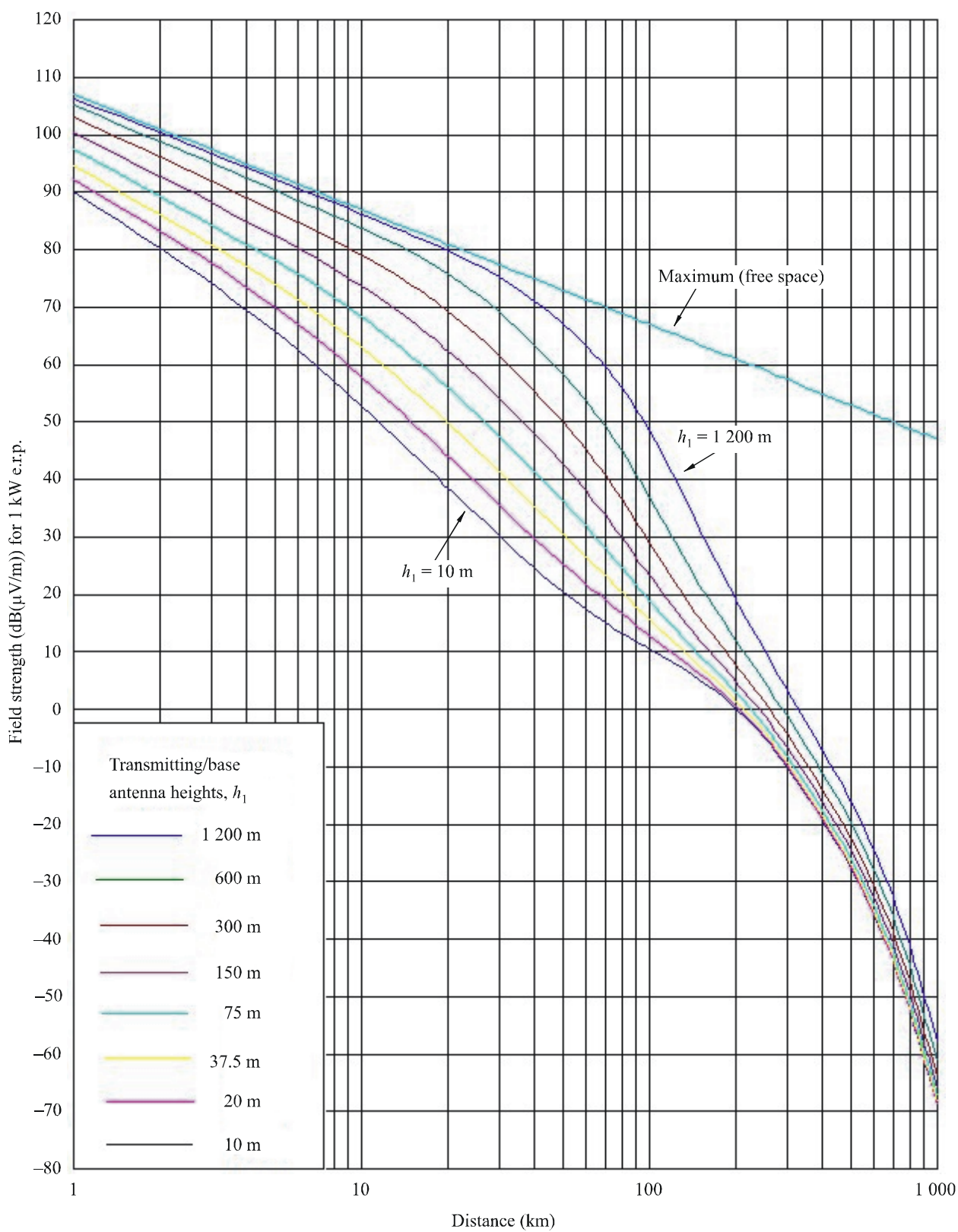
**4** The curves in Figs. 4 to 8 represent field-strength values exceeded at 50% of the locations for 50%, 10% and 1% of the time for sea paths in cold seas and warm seas, for example, those observed in the North Sea and the Mediterranean, respectively.

**5** In areas subject to pronounced super-refraction phenomena, account should be taken of the information contained in Annex 1, § 14.

**6** The ionosphere, primarily through the effects of sporadic-E ionization, can influence propagation in the lower part of the VHF band, particularly at frequencies below about 90 MHz. In some circumstances this mode of propagation may influence the field strength exceeded for small percentages of the time at distances beyond some 500 km. Near the magnetic equator and in the auroral zone, higher percentages of the time may be involved. However, these ionospheric effects can usually be ignored in most applications covered by this Recommendation and the propagation curves of this Annex have been prepared on this assumption. (Recommendation ITU-R P.534 provides guidance on sporadic-E propagation.)

FIGURE 1

100 MHz, land path, 50% time

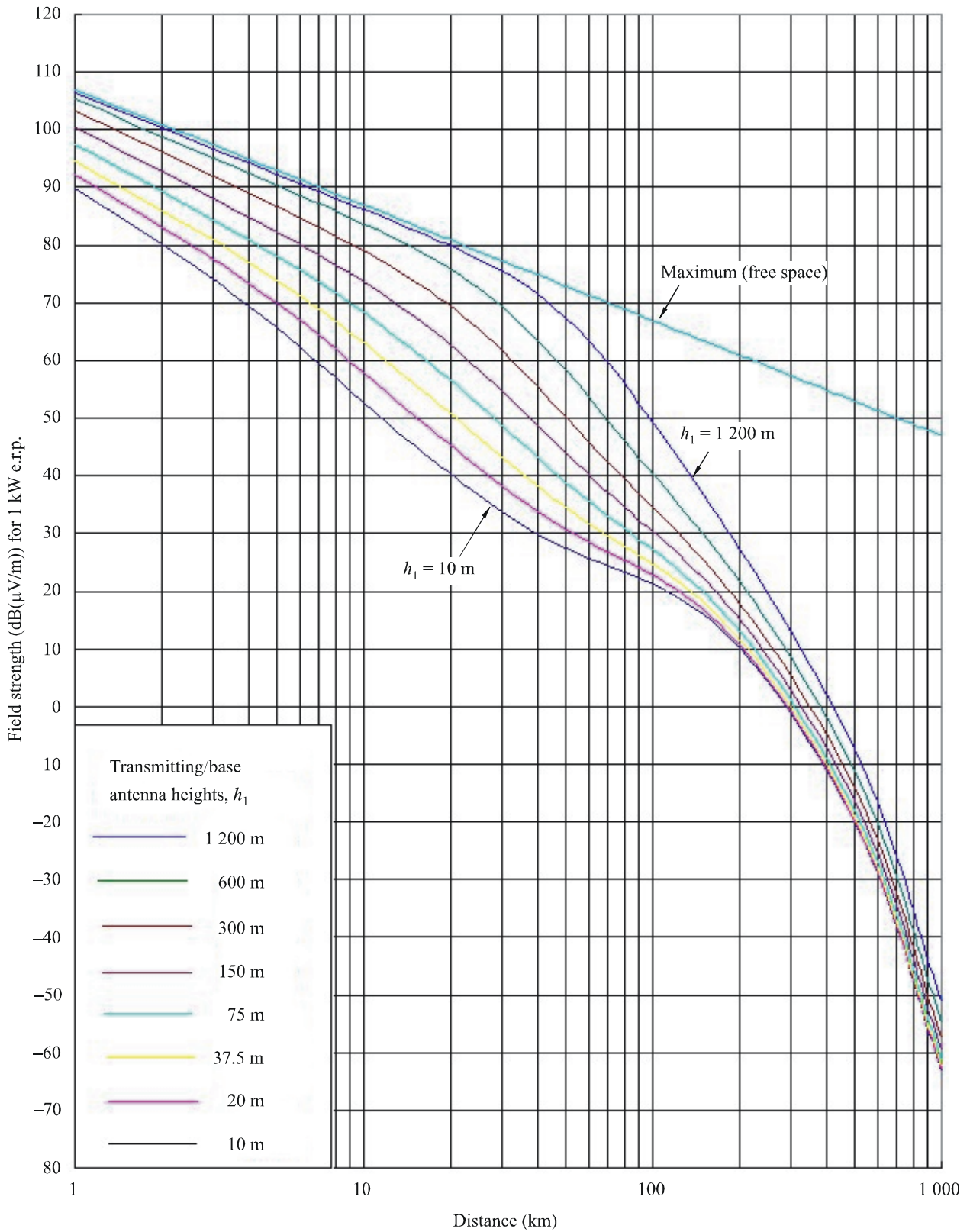


50% of locations

 $h_2$ : representative clutter height

1546-01

FIGURE 2  
100 MHz, land path, 10% time



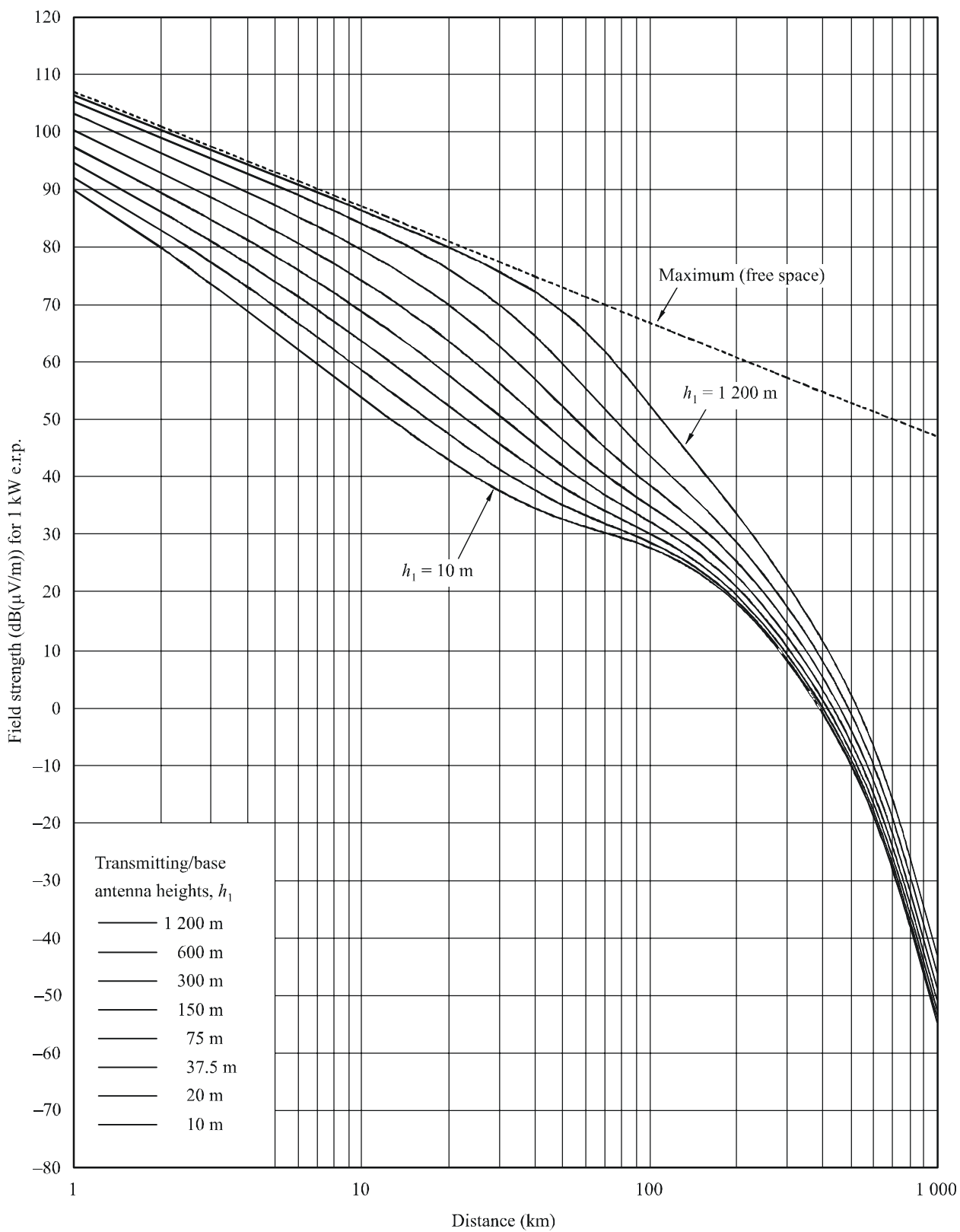
50% of locations

$h_2$ : representative clutter height

1546-02

FIGURE 3

100 MHz, land path, 1% time

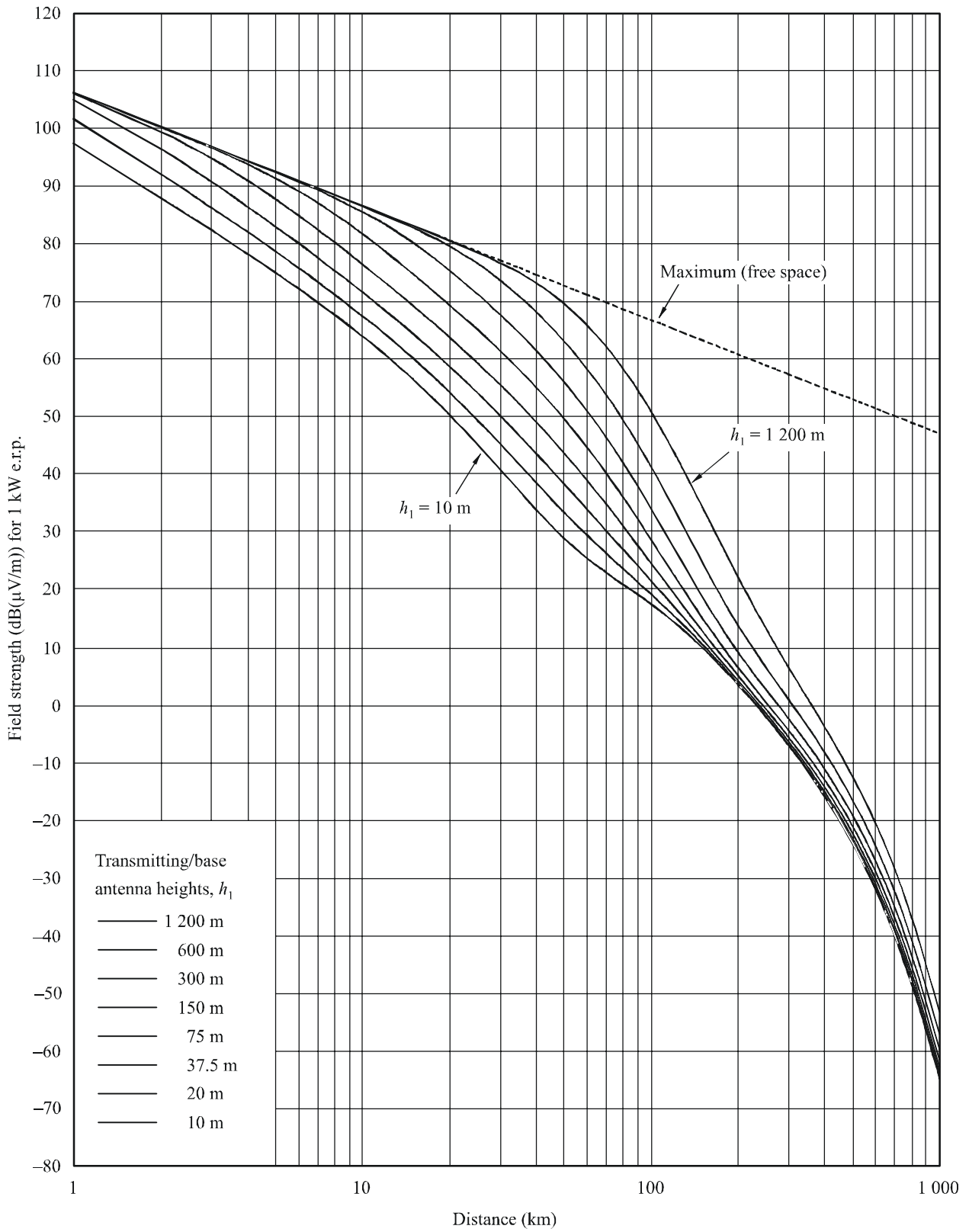


50% of locations

 $h_2$ : representative clutter height

1546-03

FIGURE 4  
100 MHz, sea path, 50% time



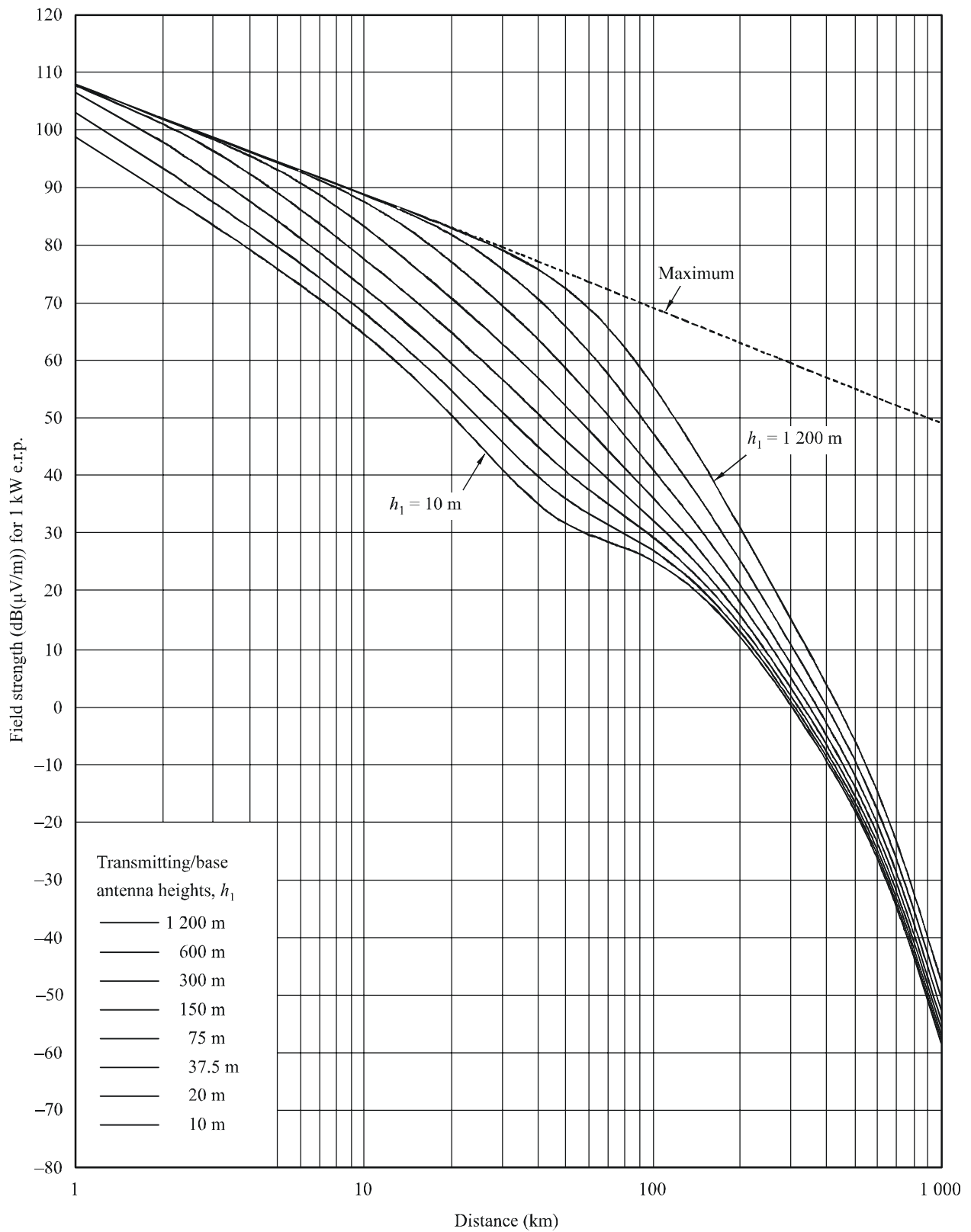
50% of locations

$h_2 = 10$  m

1546-04

FIGURE 5

100 MHz, cold sea path, 10% time

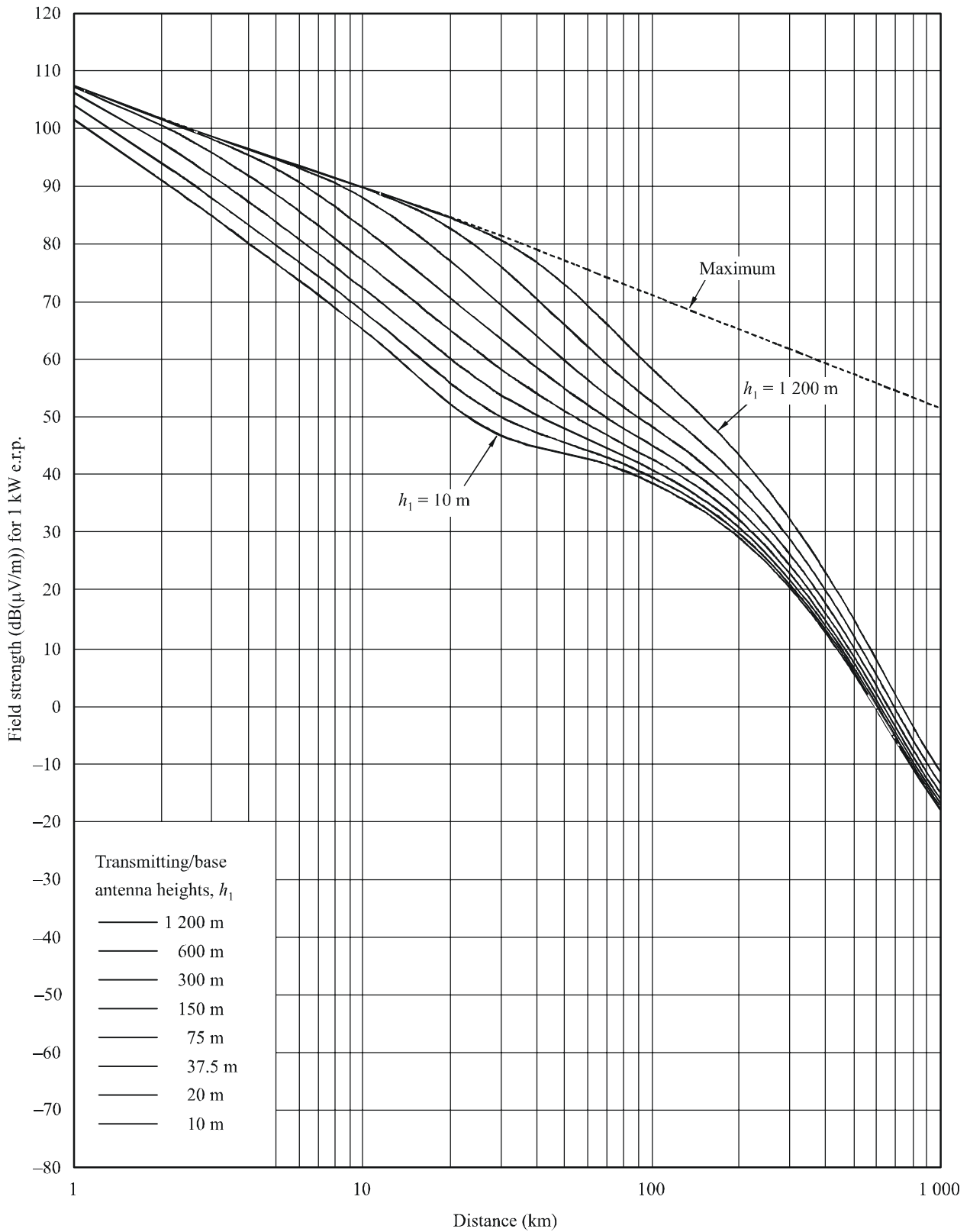


50% of locations

 $h_2 = 10$  m

1546-05

FIGURE 6  
100 MHz, cold sea path, 1% time



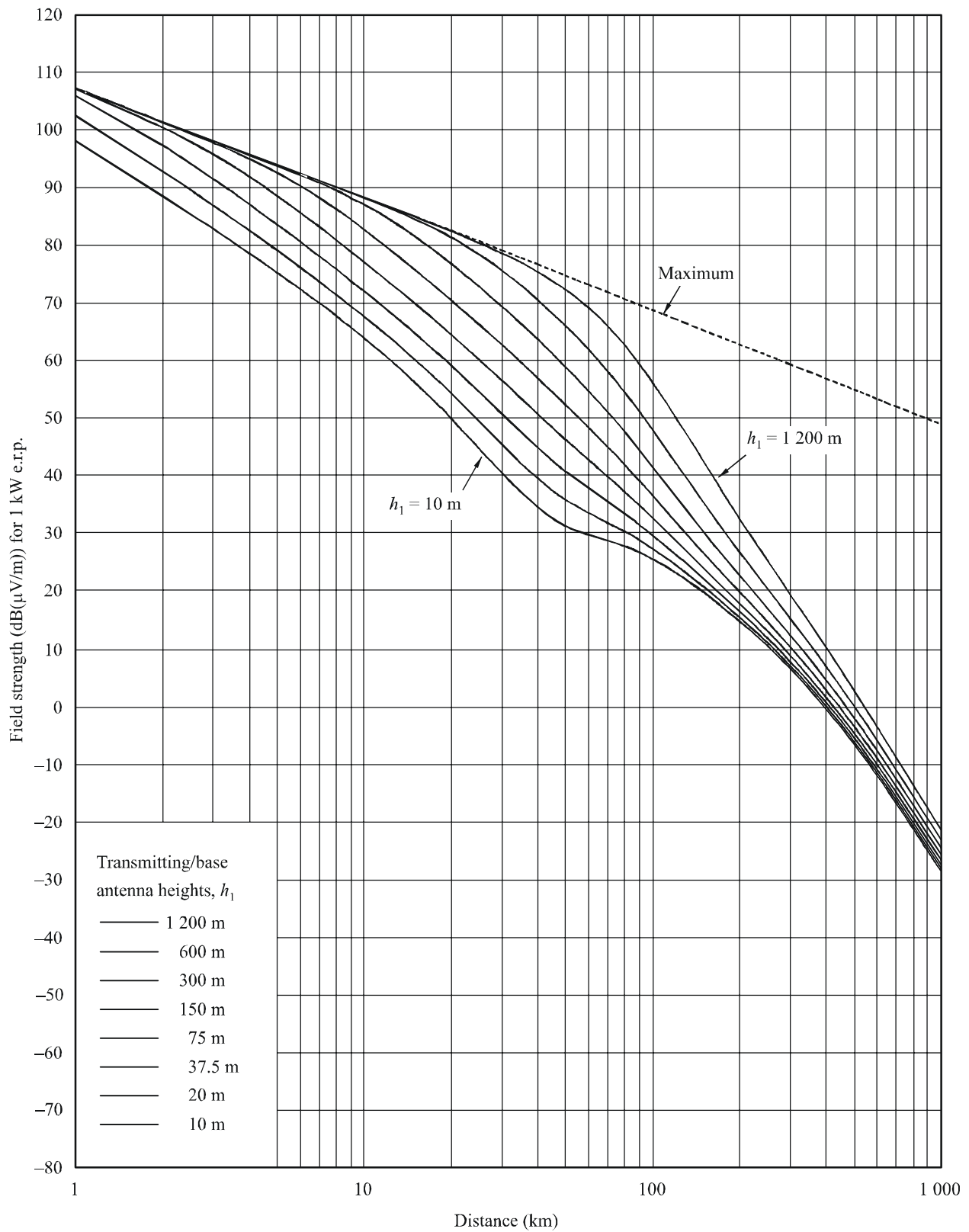
50% of locations

$h_2 = 10$  m

1546-06

FIGURE 7

100 MHz, warm sea path, 10% time



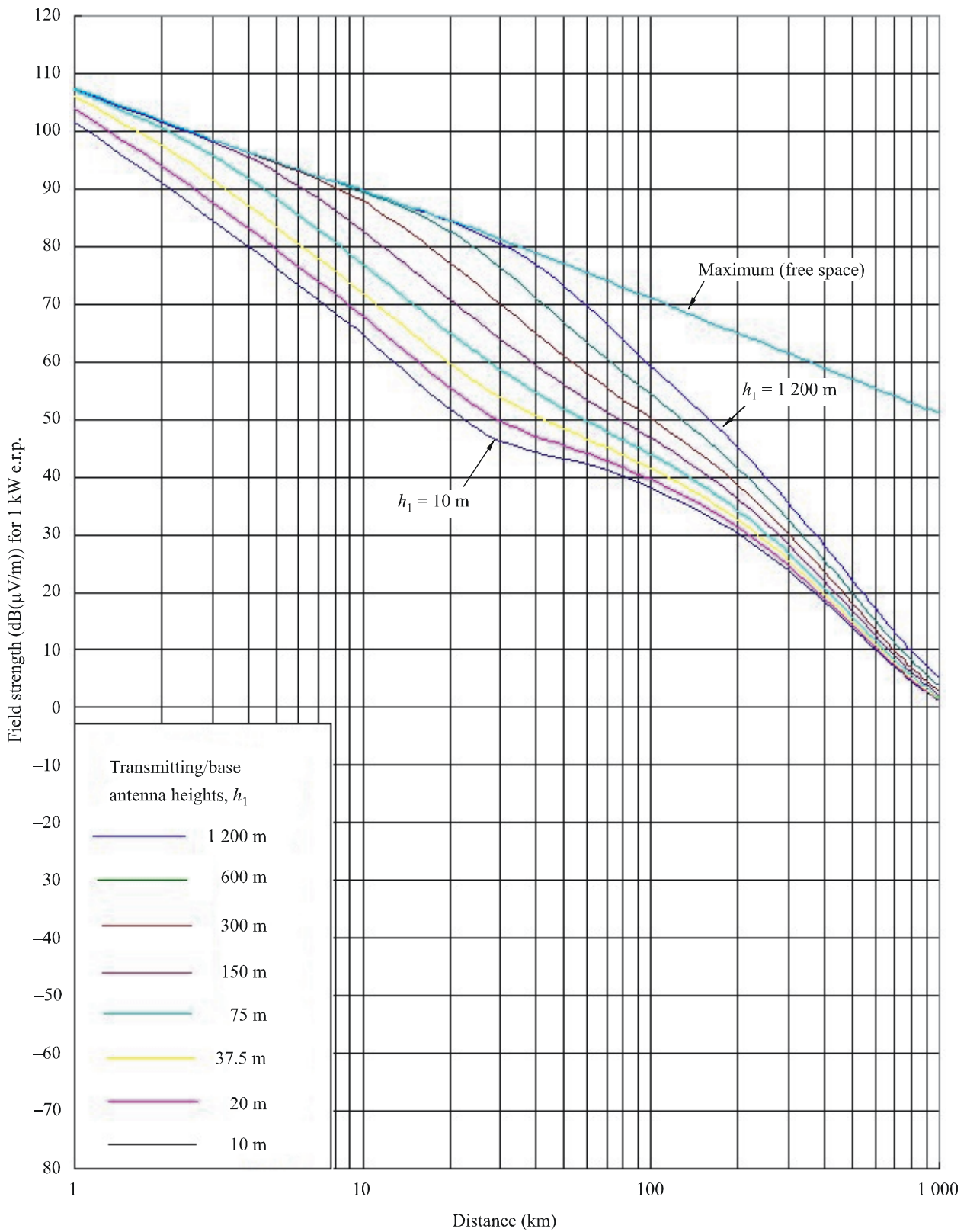
50% of locations

 $h_2 = 10$  m

1546-07

FIGURE 8

100 MHz, warm sea path, 1% time



50% of locations

 $h_2 = 10$  m

1546-08

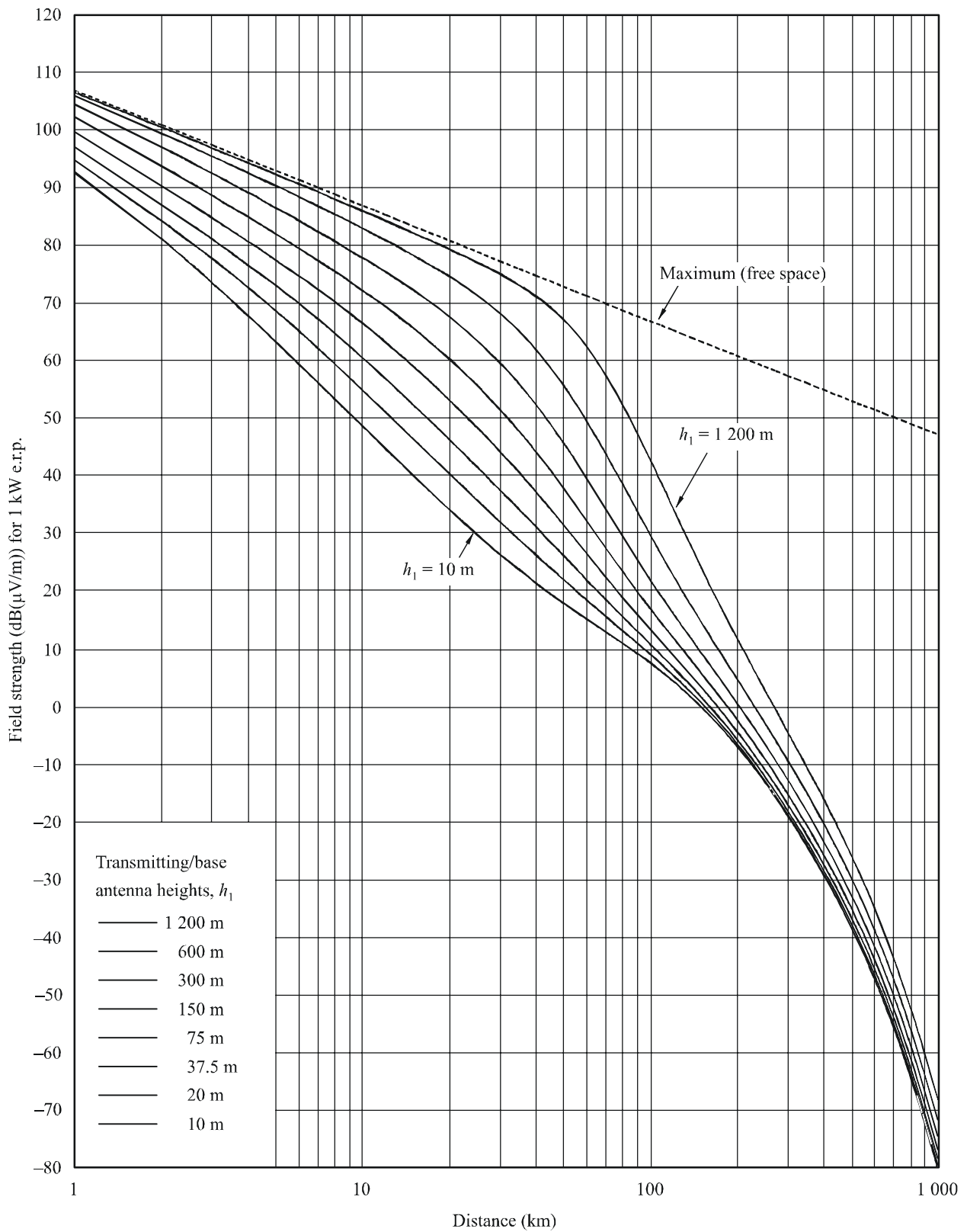
### **Annex 3**

#### **Frequency range 300 MHz to 1 000 MHz**

- 1** The field strength versus distance curves shown in this Annex are for a frequency of 600 MHz. They may be used for frequencies in the range 300 MHz to 1 000 MHz but the procedure given in Annex 5, § 6 should be used to obtain improved accuracy. The same procedure should be used when the tabulated values of field strength versus distance (see Annex 1, § 3) are employed.
- 2** The curves in Figs. 9 to 11 represent field-strength values exceeded at 50% of the locations within any area of approximately 500 m by 500 m and for 50%, 10% and 1% of the time for land paths.
- 3** The field strength distribution as a function of percentage location may be calculated using the information in Annex 5, § 12.
- 4** The curves in Figs. 12 to 16 represent field-strength values exceeded at 50% of the locations and for 50%, 10% and 1% of the time for sea paths in cold seas and warm seas, for example, those observed in the North Sea and the Mediterranean, respectively.
- 5** In areas subject to pronounced super-refraction phenomena, account should be taken of the information contained in Annex 1, § 14.

FIGURE 9

600 MHz, land path, 50% time



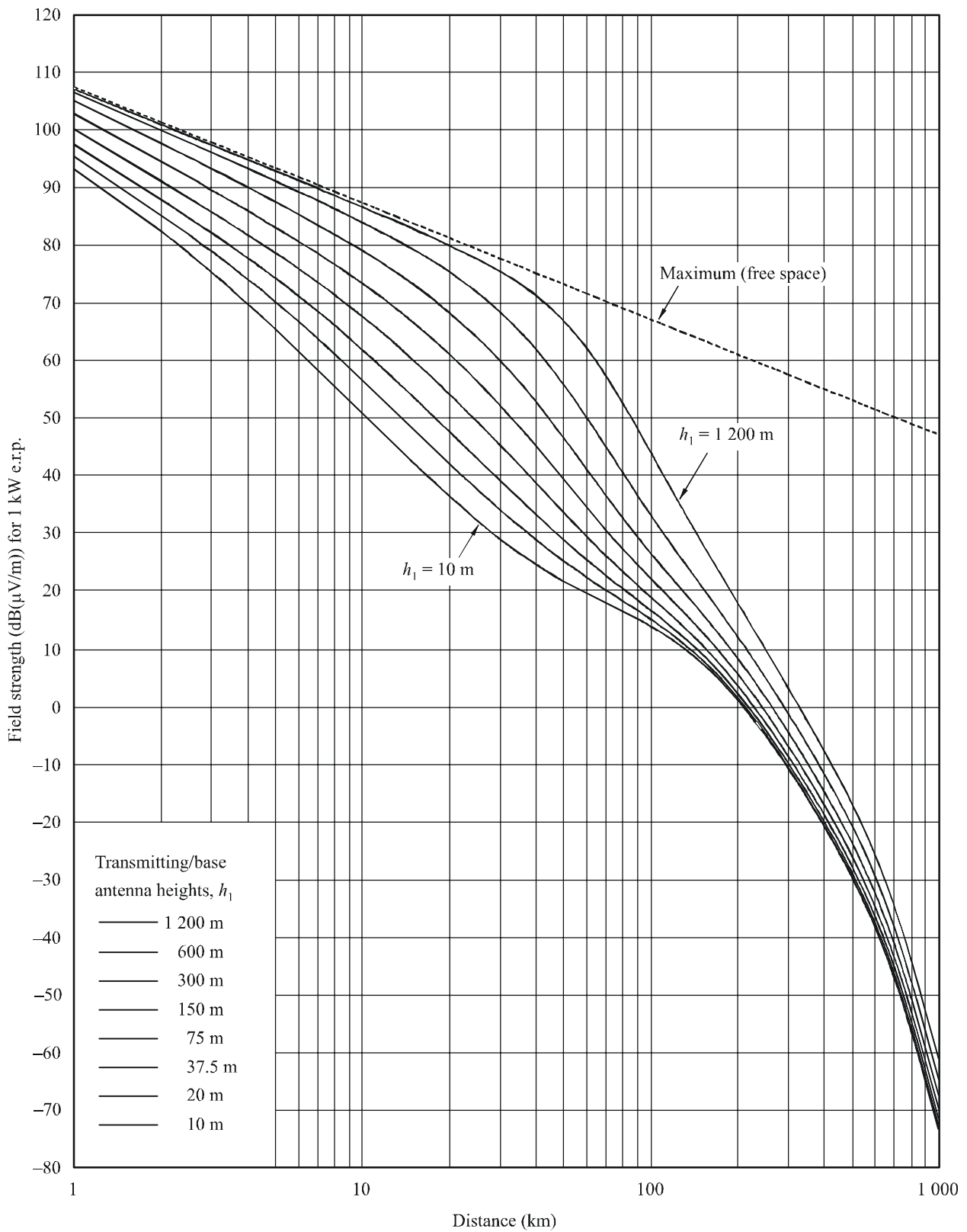
50% of locations

 $h_2$ : representative clutter height

1546-09

FIGURE 10

600 MHz, land path, 10% time

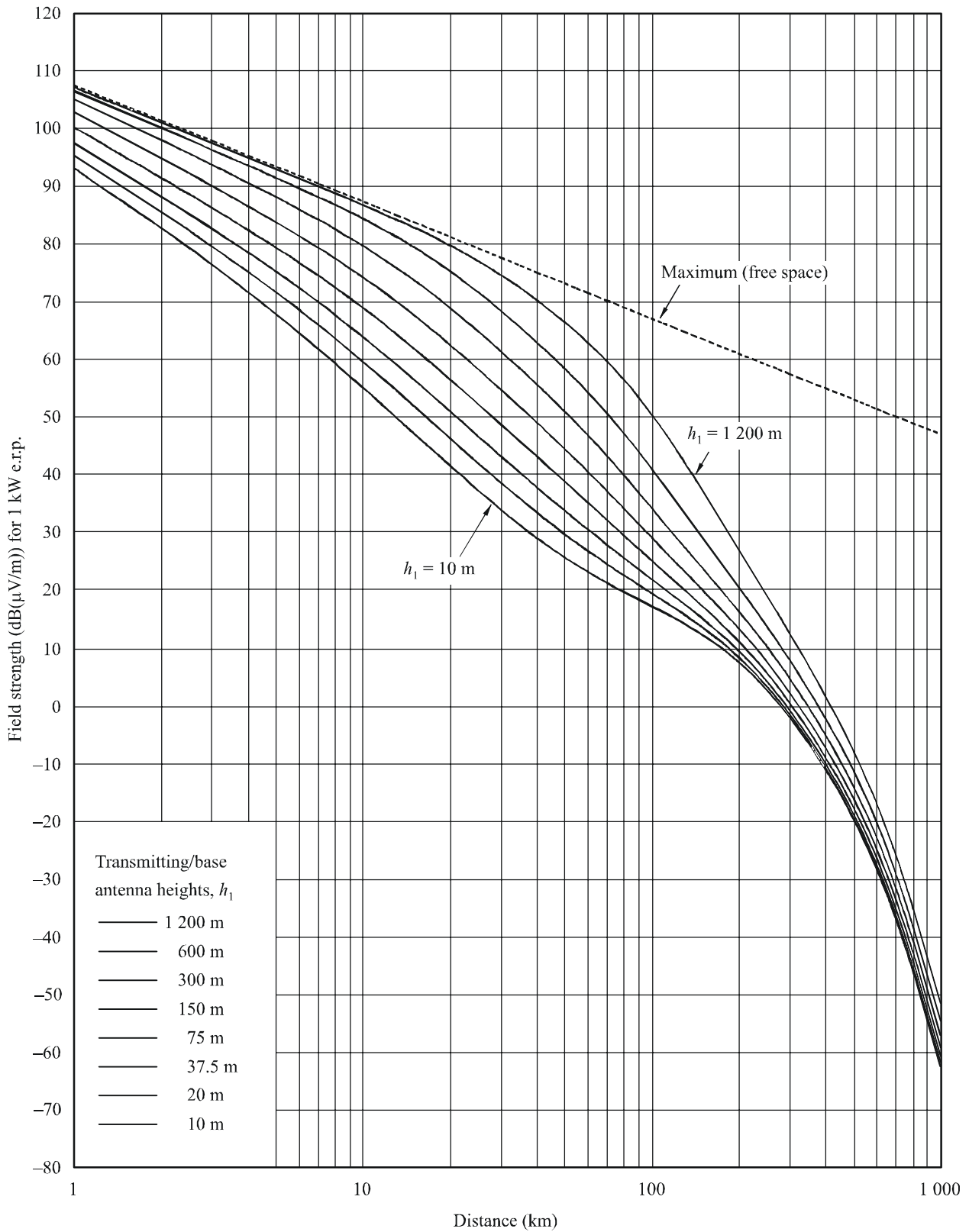


50% of locations

 $h_2$ : representative clutter height

1546-10

FIGURE 11  
600 MHz, land path, 1% time



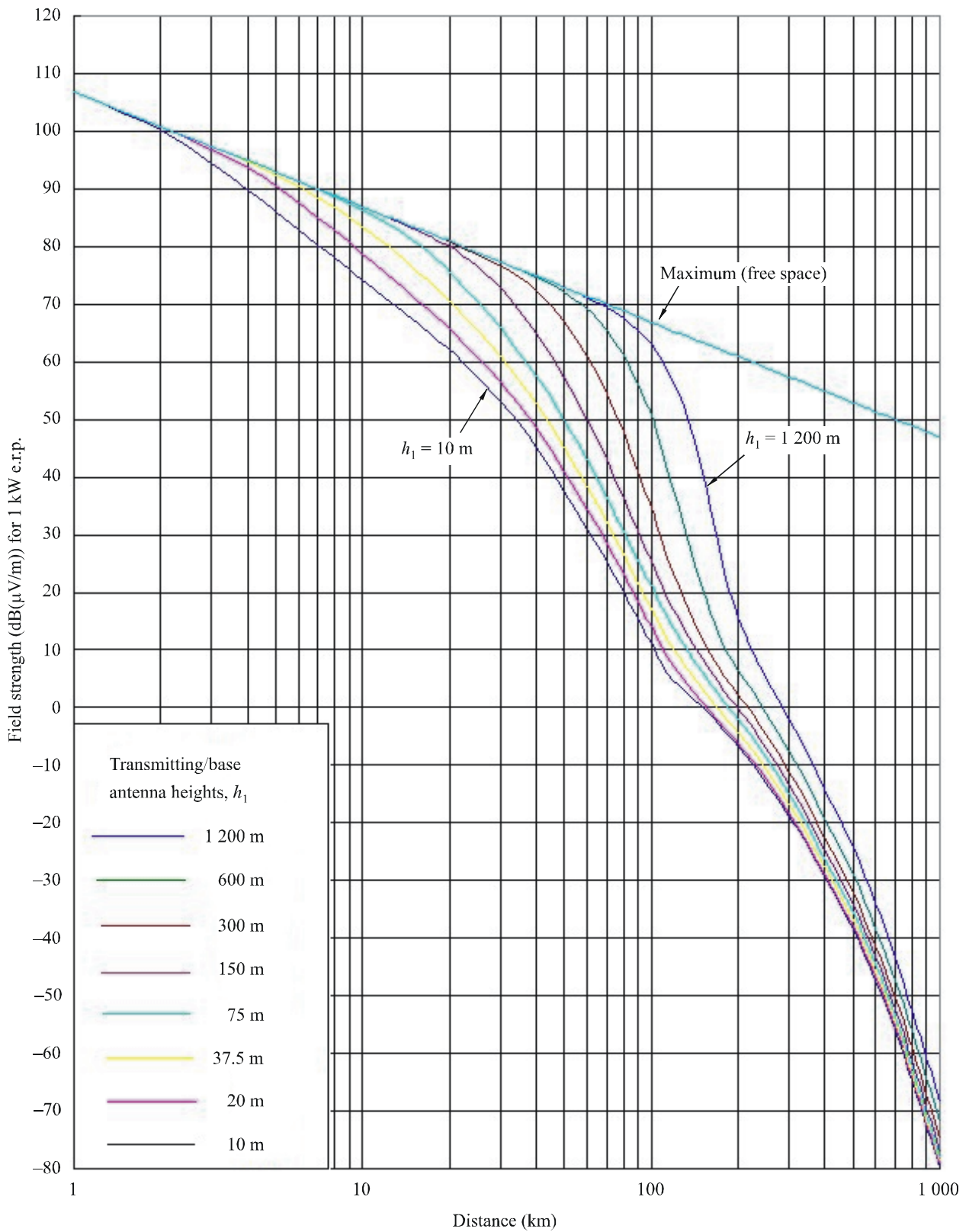
50% of locations

$h_2$ : representative clutter height

1546-11

FIGURE 12

600 MHz, sea path, 50% time



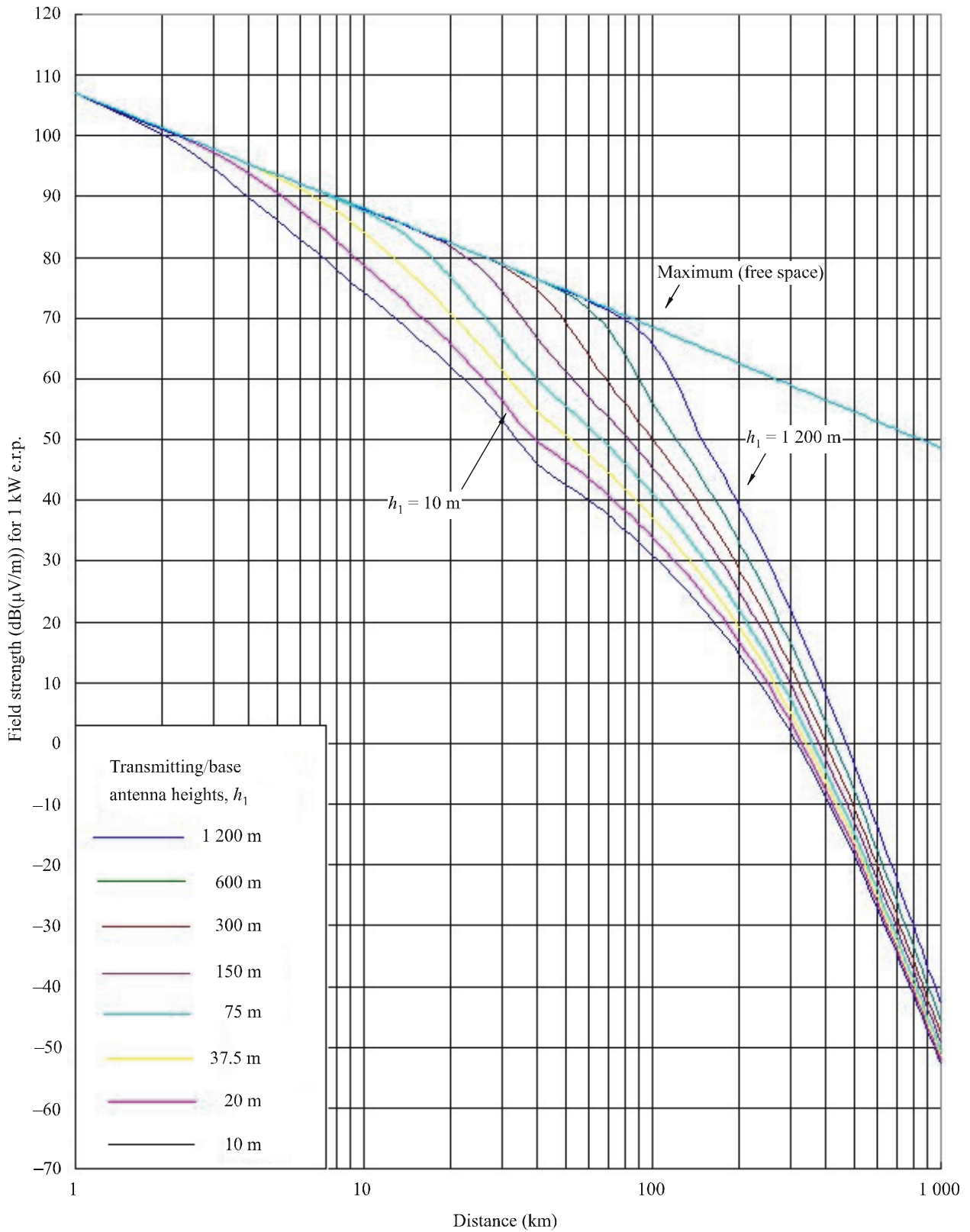
50% of locations

 $h_2 = 10$  m

1546-12

FIGURE 13

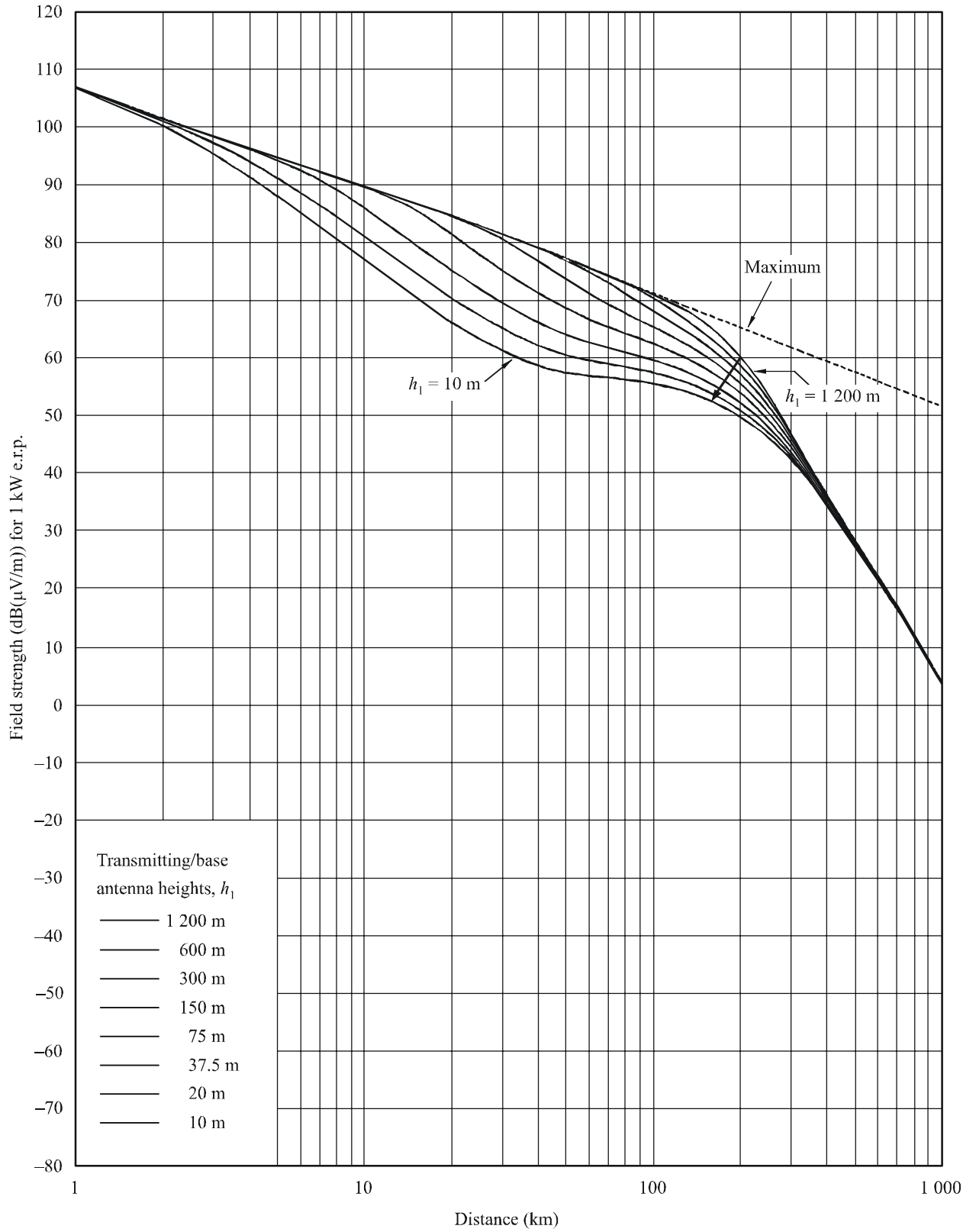
600 MHz, cold sea path, 10% time



50% of locations

$h_2 = 10\text{ m}$

FIGURE 14  
600 MHz, cold sea path, 1% time

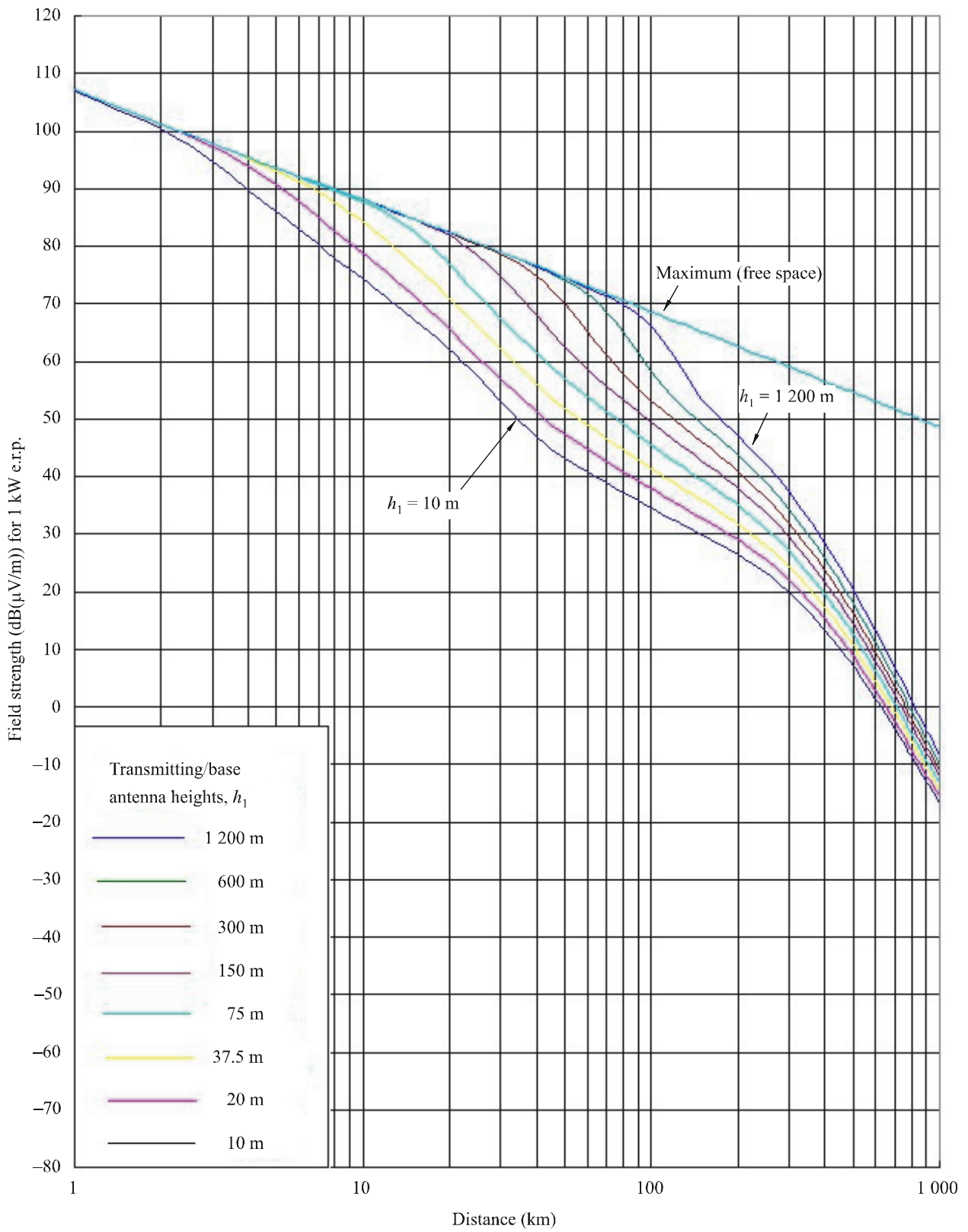


50% of locations

$h_2 = 10$  m

FIGURE 15

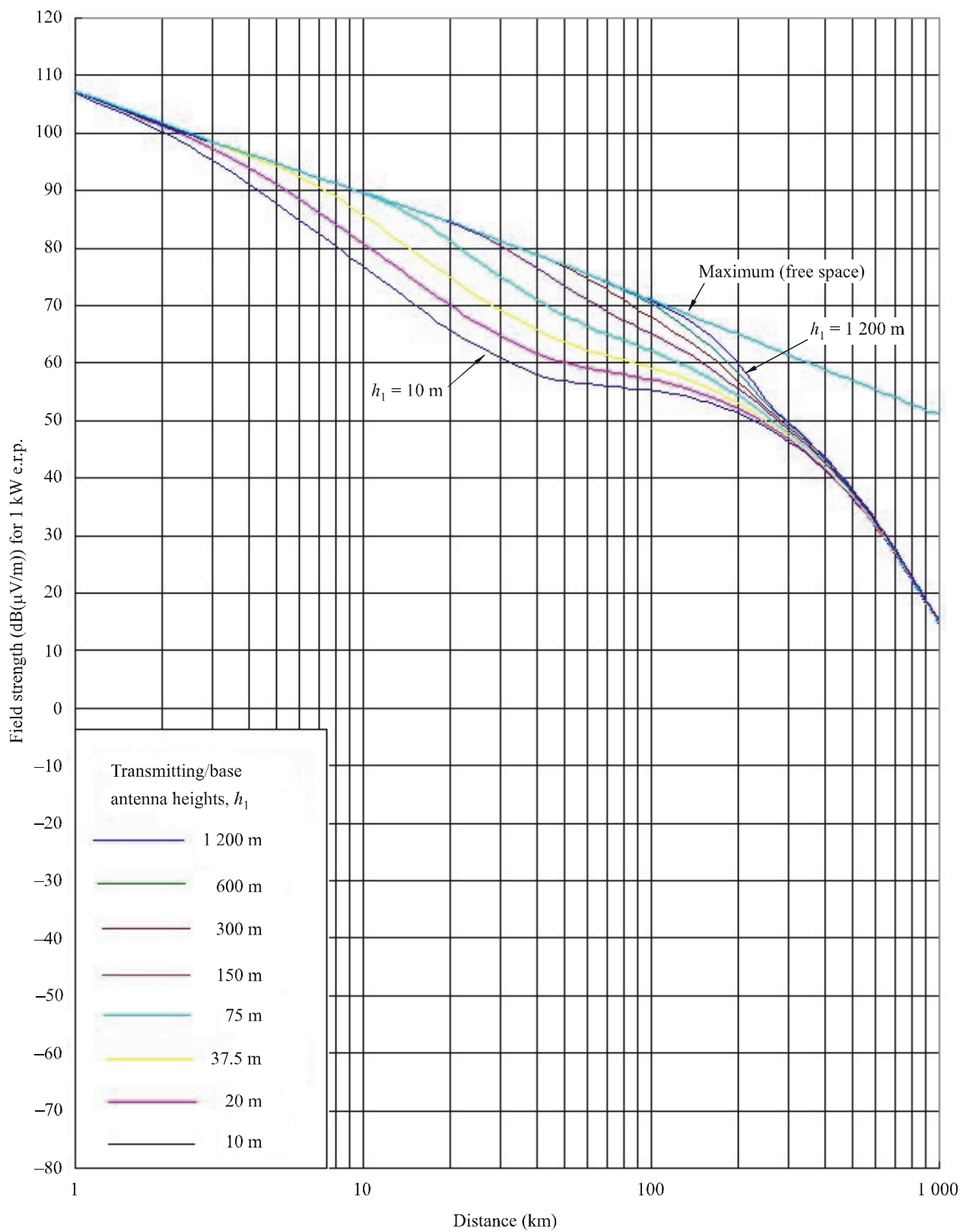
600 MHz, warm sea path, 10% time



50% of locations

$h_2 = 10$  m

FIGURE 16  
600 MHz, warm sea path, 1% time



50% of locations

$h_2 = 10\text{ m}$

## **Annex 4**

### **Frequency range 1 000 MHz to 3 000 MHz**

**1** The field strength versus distance curves shown in this Annex are for a frequency of 2 000 MHz. They may be used for frequencies in the range 1 000 MHz to 3 000 MHz but the procedure given in Annex 5, § 6 should be used to obtain improved accuracy. The same procedure should be used when the tabulated values of field strength versus distance (see Annex 1, § 3) are employed.

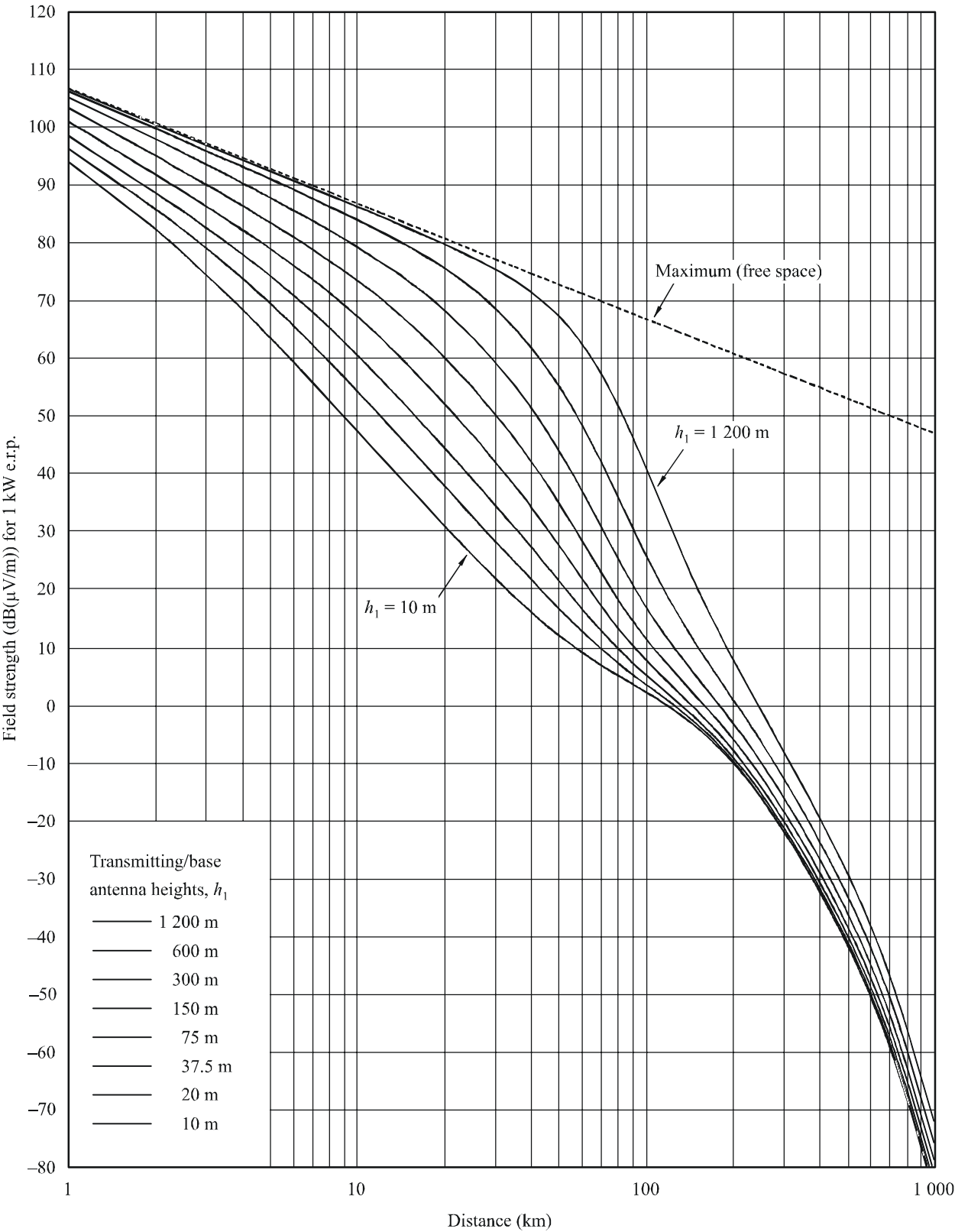
**2** The curves in Figs. 17 to 19 represent field-strength values exceeded at 50% of the locations within any area of approximately 500 m by 500 m and for 50%, 10% and 1% of the time for land paths.

**3** The field strength distribution as a function of percentage location may be calculated using the information in Annex 5, § 12.

**4** The curves in Figs. 20 to 24 represent field-strength values exceeded at 50% of the locations and for 50%, 10% and 1% of the time for sea paths in cold seas and warm seas, for example, those observed in the North Sea and the Mediterranean, respectively.

**5** In areas subject to pronounced super-refraction phenomena, account should be taken of the information contained in Annex 1, § 14.

FIGURE 17  
2 000 MHz, land path, 50% time

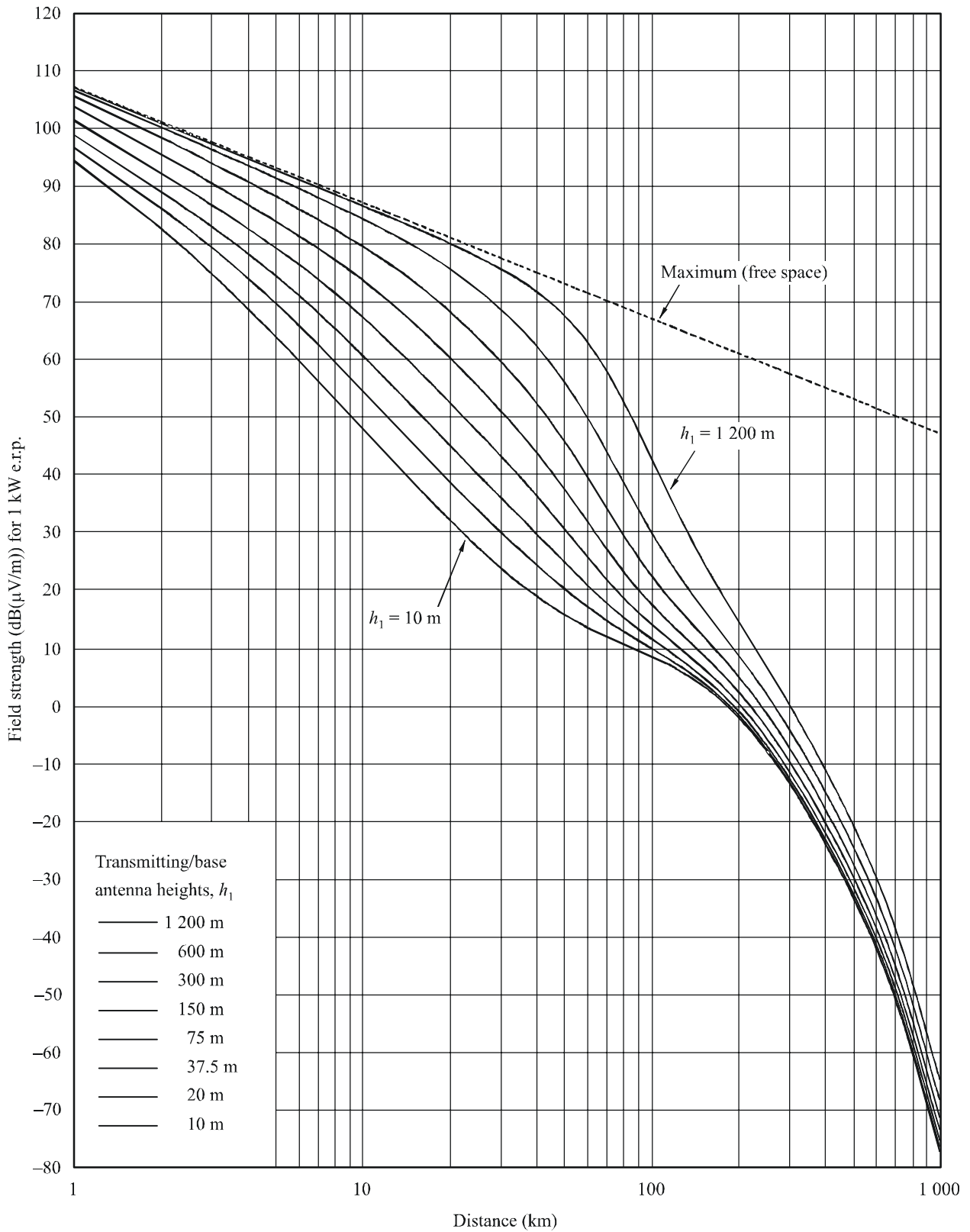


50% of locations

$h_2$ : representative clutter height

FIGURE 18

2 000 MHz, land path, 10% time

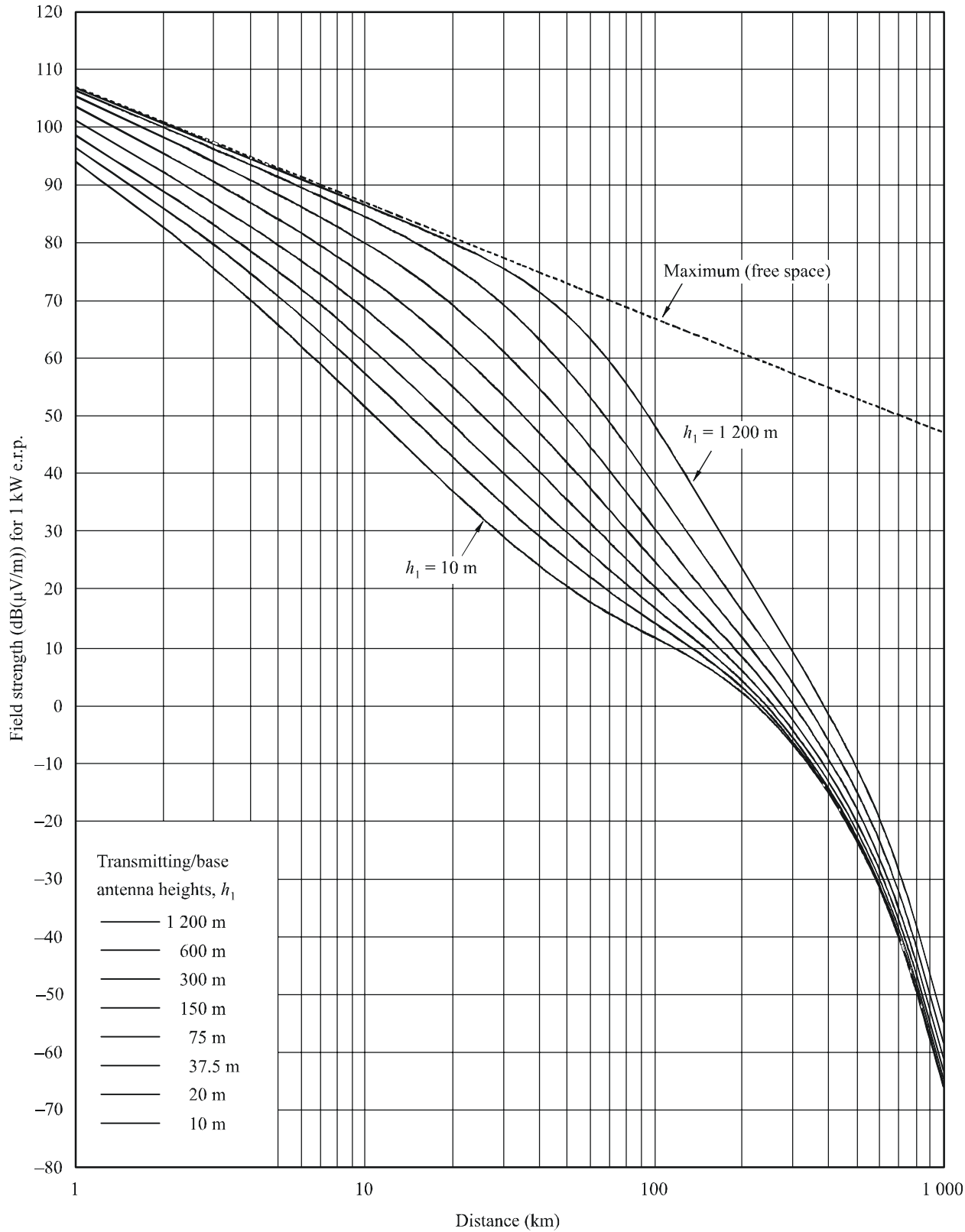


50% of locations

 $h_2$ : representative clutter height

1546-18

FIGURE 19  
2 000 MHz, land path, 1% time

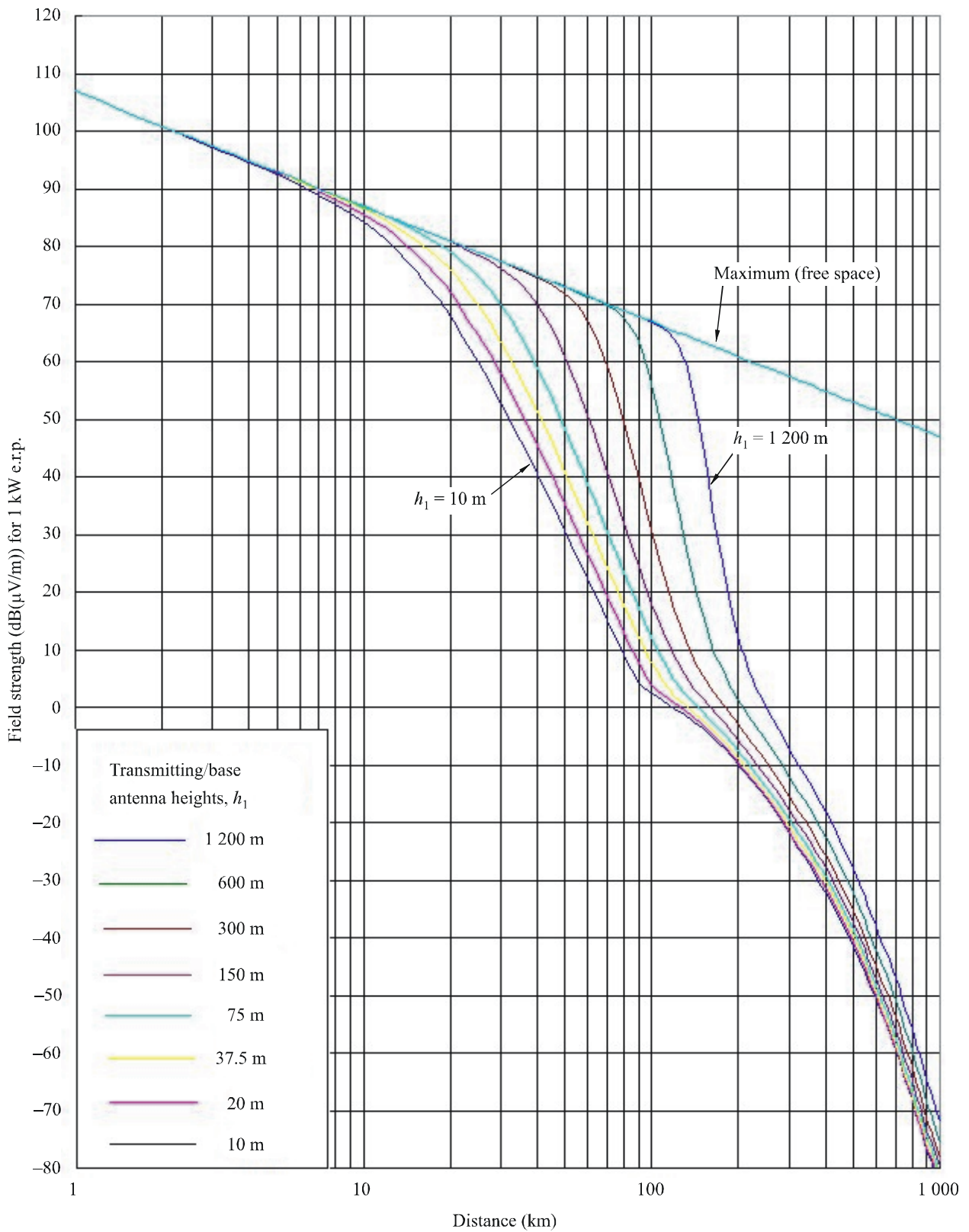


50% of locations

$h_2$ : representative clutter height

FIGURE 20

2 000 MHz, sea path, 50% time

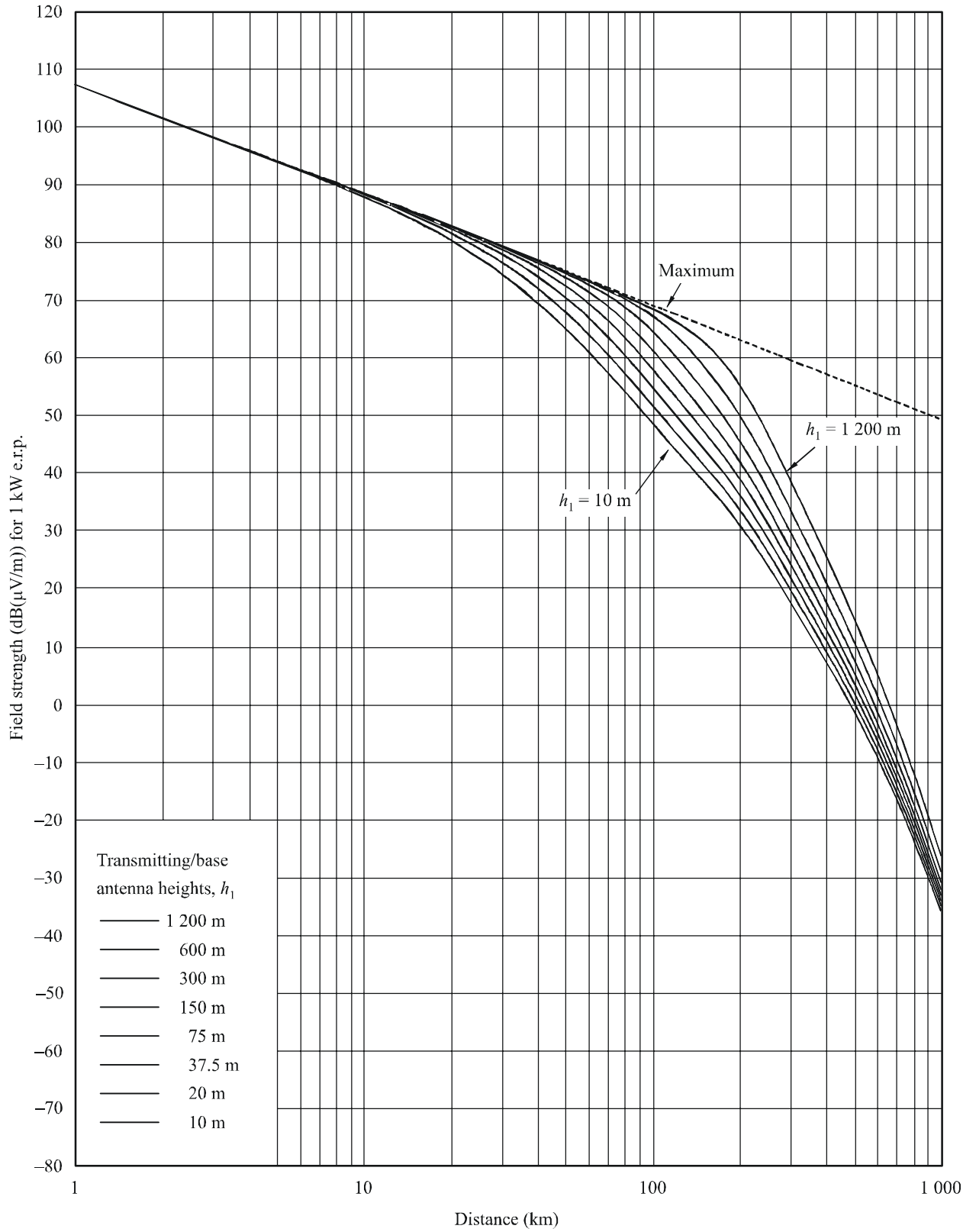


50% of locations

 $h_2 = 10$  m

1546-20

FIGURE 21  
2 000 MHz, cold sea path, 10% time

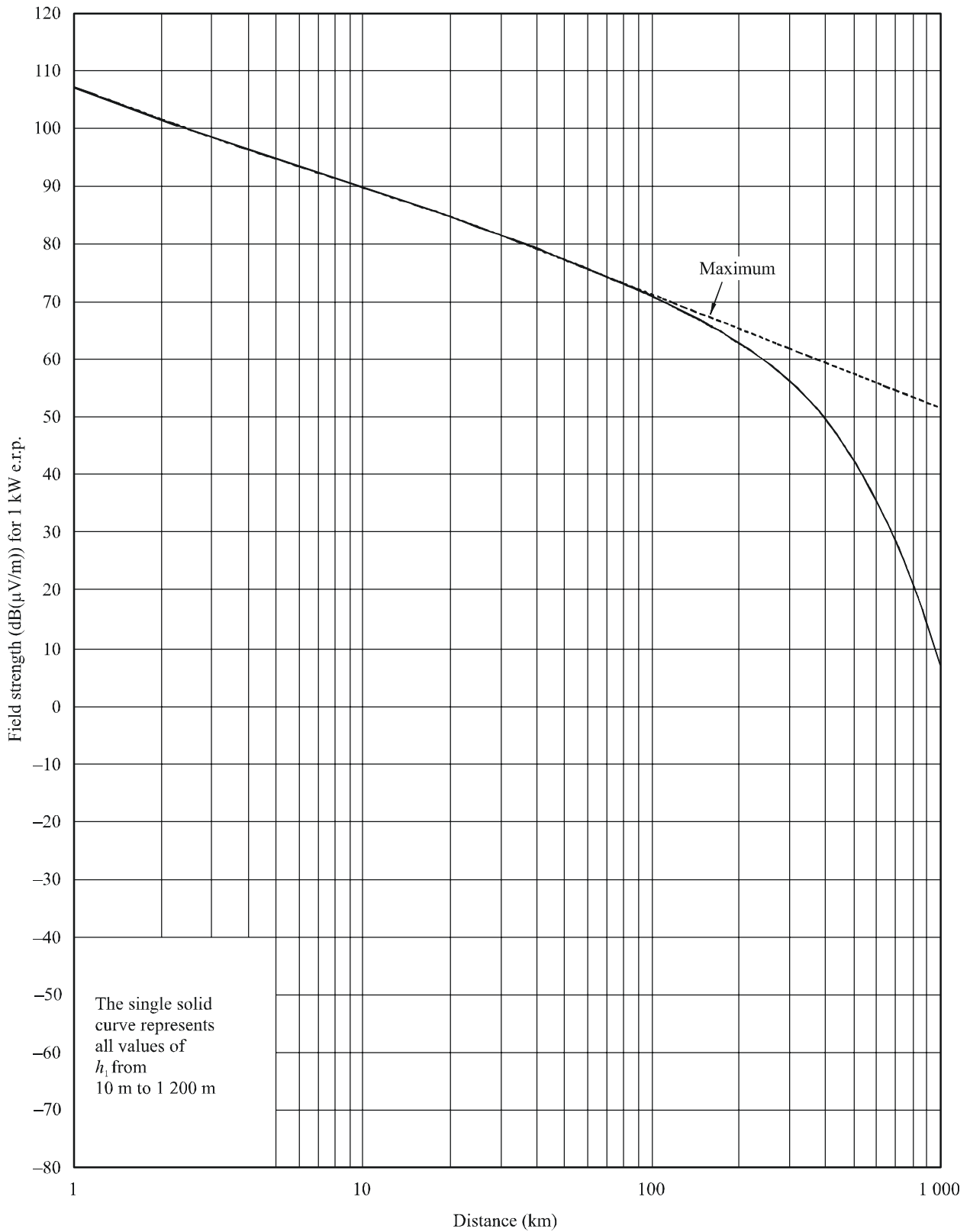


50% of locations

$h_2 = 10$  m

FIGURE 22

2 000 MHz, cold sea path, 1% time



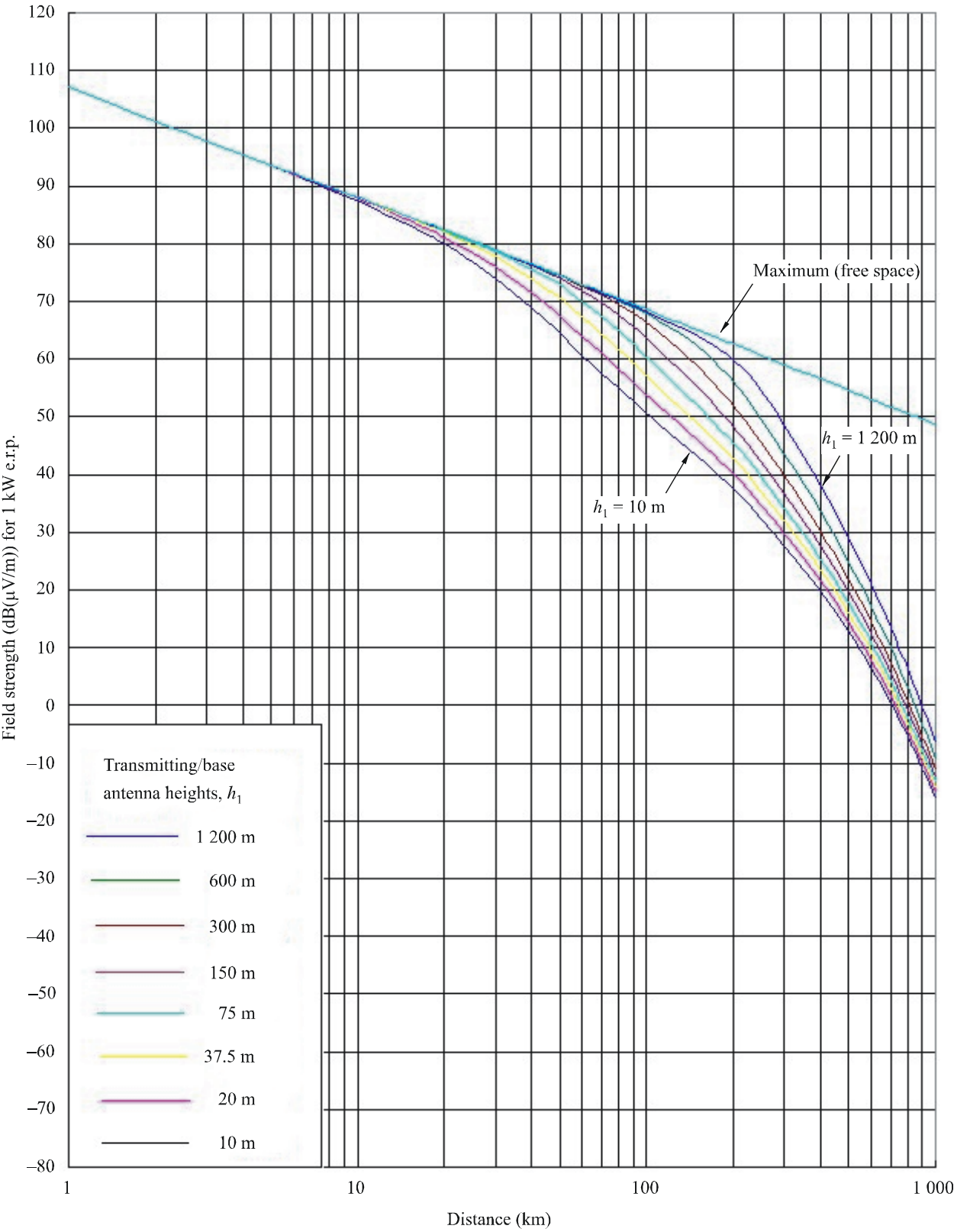
50% of locations

$h_2 = 10$  m

1546-22

FIGURE 23

2 000 MHz, warm sea path, 10% time

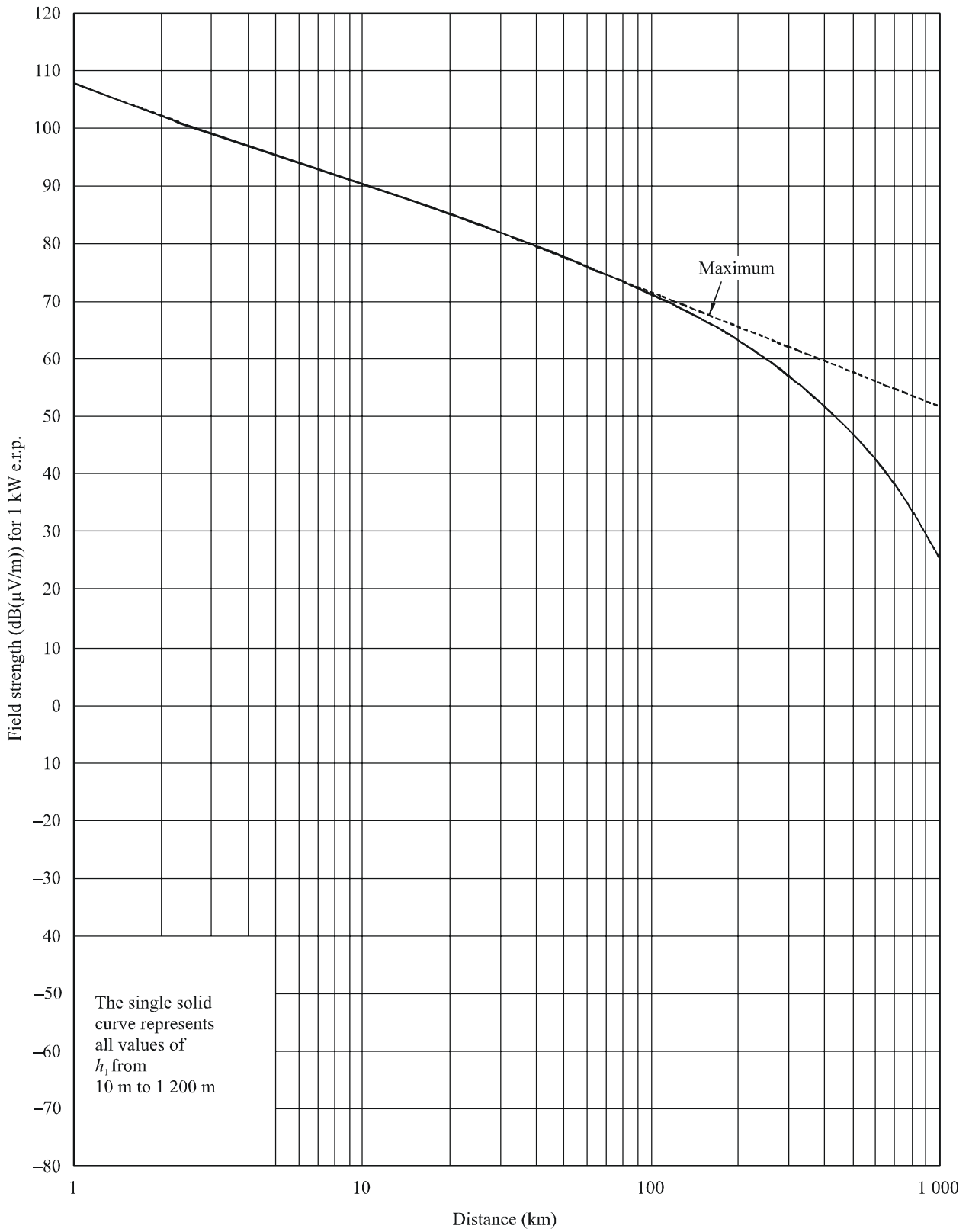


50% of locations

$h_2 = 10$  m

FIGURE 24

2 000 MHz, warm sea path, 1% time



50% of locations

$h_2 = 10$  m

1546-24

## Annex 5

### Additional information and methods for implementing the prediction method

#### 1 Introduction

This Annex describes separate stages of the calculation. A step-by-step description of the overall method is given in Annex 6.

Sections 2 to 7 of this Annex describe how field strengths are extracted from the curve families with interpolation for distance,  $h_1$ , frequency and percentage time. Section 8 describes how field strengths are combined for a mixed land-sea path. Sections 9 to 13 describe corrections which can be added to the field strength predictions for additional precision. Sections 14 to 17 provide auxiliary information.

#### 1.1 The terminal designations

This Recommendation is not reciprocal with respect to designations of the transmitting/base station and the receiver/mobile station/terminal. This Recommendation is primarily intended for use with broadcasting and mobile services where the transmitter/base antenna is above the level of local clutter. When this Recommendation is used to calculate the coverage of, or for the coordination of, broadcasting and/or base-to-mobile stations, then the actual transmitting/base station should be treated as the “transmitting/base”. In other cases where there is no *a priori* reason to consider either terminal as the transmitting/base, then the selection of which terminal to designate as the transmitting/base station for the purposes of this Recommendation can be as follows:

- a) if both terminals are below the levels of clutter in their respective vicinities, then this Recommendation will not give accurate predictions to the problem at hand. Users should seek guidance from other, more appropriate, ITU-R Recommendations;
- b) if one terminal is in an open location or above the surrounding clutter, whereas the other terminal is below the level of clutter, then the open/uncluttered terminal should be treated as the transmitting/base station for the purposes of actual identity as the transmitter/base or receiver/mobile;
- c) if both terminals are open/uncluttered, then the terminal with the greater effective height should be treated as the transmitting/base station for the purposes of this Recommendation.

As noted above, this Recommendation is not reciprocal. However, in some special cases, it may be treated as such. For these particular cases, for example, which may be encountered for the monitoring and prediction of receiver/mobile-to-transmitter/base coverage and/or interference, it may be useful, under items b) and c) of the previous discussion, to designate that terminal in the open location, which should also always have the higher effective height, as the transmitter/base as the “high” antenna, whilst designating the terminal in the cluttered location as the receiver/mobile as the “low” antenna, without regard to which terminal is actually the transmitter/base and receiver/mobile. Users of this Recommendation should note, for the purposes of calculation, that if these “high” and “low” designations are to be used, the high antenna termination will always be synonymous with (and equivalent to) the transmitter/base station’s effective height,  $h_1$ , whilst the low antenna termination will always be synonymous with (and equivalent to) the receiver/mobile’s height,  $h_2$ , with the same qualifier, in the subsequent calculation of field strength or basic transmission loss.

## 2 Maximum field-strength values

A field strength must not exceed a maximum value,  $E_{max}$ , given by:

$$E_{max} = E_{fs} \quad \text{dB}(\mu\text{V/m}) \quad \text{for land paths} \quad (1a)$$

$$E_{max} = E_{fs} + E_{se} \quad \text{dB}(\mu\text{V/m}) \quad \text{for sea paths} \quad (1b)$$

where  $E_{fs}$  is the free space field strength for 1 kW e.r.p. given by:

$$E_{fs} = 106.9 - 20 \log(d) \quad \text{dB}(\mu\text{V/m}) \quad (2)$$

and  $E_{se}$  is an enhancement for sea curves given by:

$$E_{se} = 2.38 \{1 - \exp(-d/8.94)\} \log(50/t) \quad \text{dB} \quad (3)$$

where:

$d$ : distance (km)

$t$ : percentage time.

In principle any correction which increases a field strength must not be allowed to produce values greater than these limits for the family of curves and distance concerned. However, limitation to maximum values should be applied only where indicated in Annex 6.

## 3 Determination of transmitting/base antenna height, $h_1$

The transmitting/base antenna height,  $h_1$ , to be used in calculation depends on the type and length of the path and on various items of height information, which may not all be available.

For sea paths  $h_1$  is the height of the antenna above sea level.

For land paths, the effective height of the transmitting/base antenna,  $h_{eff}$ , is defined as its height in metres over the average level of the ground between distances of 3 and 15 km from the transmitting/base antenna in the direction of the receiving/mobile antenna. Where the value of effective transmitting/base antenna height,  $h_{eff}$ , is not known it should be estimated from general geographic information. This Recommendation is not valid when the transmitting/base antenna is below the height of surrounding clutter.

The value of  $h_1$  to be used in calculation should be obtained using the method given in § 3.1, 3.2 or in § 3.3 as appropriate.

### 3.1 Land paths shorter than 15 km

For land paths less than 15 km one of the following two methods should be used:

#### 3.1.1 Terrain information not available

Where no terrain information is available when propagation predictions are being made, the value of  $h_1$  is calculated according to path length,  $d$ , as follows:

$$h_1 = h_a \quad \text{m} \quad \text{for} \quad d \leq 3 \text{ km} \quad (4)$$

$$h_1 = h_a + (h_{eff} - h_a)(d - 3)/12 \quad \text{m} \quad \text{for} \quad 3 \text{ km} < d < 15 \text{ km} \quad (5)$$

where  $h_a$  is the antenna height above ground (e.g. height of the mast).

### 3.1.2 Terrain information available

Where terrain information is available when propagation predictions are being made:

$$h_1 = h_b \quad \text{m} \quad (6)$$

where  $h_b$  is the height of the antenna above terrain height averaged between  $0.2d$  and  $d$  km.

### 3.2 Land paths of 15 km or longer

For these paths:

$$h_1 = h_{eff} \quad \text{m} \quad (7)$$

### 3.3 Sea paths

The concept of  $h_1$  for an all-sea path is that it represents the physical height of the antenna above the surface of the sea. This Recommendation is not reliable in the case of a sea path for  $h_1$  values less than about 3 m, and an absolute lower limit of 1 m should be observed.

## 4 Application of transmitting/base antenna height, $h_1$

The value of  $h_1$  controls which curve or curves are selected from which to obtain field-strength values, and the interpolation or extrapolation which may be necessary. The following cases are distinguished.

### 4.1 Transmitting/base antenna height, $h_1$ , in the range 10 m to 3 000 m

If the value of  $h_1$  coincides with one of the eight heights for which curves are provided, namely 10, 20, 37.5, 75, 150, 300, 600 or 1 200 m, the required field strength may be obtained directly from the plotted curves or the associated tabulations. Otherwise the required field strength should be interpolated or extrapolated from field strengths obtained from two curves using:

$$E = E_{inf} + (E_{sup} - E_{inf}) \log(h_1 / h_{inf}) / \log(h_{sup} / h_{inf}) \quad \text{dB}(\mu\text{V/m}) \quad (8)$$

where:

- $h_{inf}$ : 600 m if  $h_1 > 1\,200$  m, otherwise the nearest nominal effective height below  $h_1$
- $h_{sup}$ : 1 200 m if  $h_1 > 1\,200$  m, otherwise the nearest nominal effective height above  $h_1$
- $E_{inf}$ : field-strength value for  $h_{inf}$  at the required distance
- $E_{sup}$ : field-strength value for  $h_{sup}$  at the required distance.

The field strength resulting from extrapolation for  $h_1 > 1\,200$  m should be limited if necessary such that it does not exceed the maximum defined in § 2.

This Recommendation is not valid for  $h_1 > 3\,000$  m.

### 4.2 Transmitting/base antenna height, $h_1$ , in the range 0 m to 10 m

The method when  $h_1$  is less than 10 m depends on whether the path is over land or sea.

*For a land path:*

For a land path the field strength at the required distance  $d$  km for  $0 \leq h_1 < 10$  m is calculated using:

$$E = E_{zero} + 0.1h_1(E_{10} - E_{zero}) \quad \text{dB}(\mu\text{V/m}) \quad (9)$$

where:

$$E_{zero} = E_{10} + 0.5(C_{1020} + C_{h1neg10}) \quad \text{dB}(\mu\text{V/m}) \quad (9a)$$

$$C_{1020} = E_{10} - E_{20} \quad \text{dB} \quad (9b)$$

$C_{h1neg10}$ : the correction  $C_{h1}$  in dB calculated using equation (12) in § 4.3 below at the required distance for  $h_1 = -10$  m

$E_{10}$  and  $E_{20}$ : the field strengths in dB( $\mu\text{V/m}$ ) calculated according to § 4.1 above at the required distance for  $h_1 = 10$  m and  $h_1 = 20$  m respectively.

Note that the corrections  $C_{1020}$  and  $C_{h1neg10}$  should both evaluate to negative quantities.

*For a sea path:*

Note that for a sea path,  $h_1$  should not be less than 1 m. The procedure requires the distance at which the path has 0.6 of the first Fresnel zone just unobstructed by the sea surface. This is given by:

$$D_{h1} = D_{06}(f, h_1, 10) \quad \text{km} \quad (10a)$$

where  $f$  is the nominal frequency (MHz) and the function  $D_{06}$  is defined in § 17.

If  $d > D_{h1}$  it will be necessary to also calculate the 0.6 Fresnel clearance distance for a sea path where the transmitting/base antenna height is 20 m, given by:

$$D_{20} = D_{06}(f, 20, 10) \quad \text{km} \quad (10b)$$

The field strength for the required distance,  $d$ , and value of  $h_1$ , is then given by:

$$E = E_{max} \quad \text{dB}(\mu\text{V/m}) \quad \text{for} \quad d \leq D_{h1} \quad (11a)$$

$$= E_{Dh1} = (E_{D20} - E_{Dh1}) \log(d/D_{h1}) / \log(D_{20}/D_{h1}) \quad \text{dB}(\mu\text{V/m}) \quad \text{for} \quad D_{h1} < d < D_{20} \quad (11b)$$

$$= E'(1 - F_s) + E''F_s \quad \text{dB}(\mu\text{V/m}) \quad \text{for} \quad d \geq D_{20} \quad (11c)$$

where:

$E_{max}$ : maximum field strength at the required distance given in § 2

$E_{Dh1}$ :  $E_{max}$  for distance  $D_{h1}$  as given in § 2

$E_{D20} = E_{10}(D_{20}) + (E_{20}(D_{20}) - E_{10}(D_{20})) \log(h_1/10) / \log(20/10)$

$E_{10}(x)$ : field strength for  $h_1 = 10$  m interpolated for distance  $x$

$E_{20}(x)$ : field strength for  $h_1 = 20$  m interpolated for distance  $x$

$E' = E_{10}(d) + (E_{20}(d) - E_{10}(d)) \log(h_1/10) / \log(20/10)$

$E''$ : field strength for distance  $d$  calculated using equation (9)

$F_s = (d - D_{20})/d$ .

#### 4.3 Negative values of transmitting/base antenna height, $h_1$

For land paths it is possible for the effective transmitting/base antenna height  $h_{eff}$  to have a negative value, since it is based on the average terrain height at distances from 3 km to 15 km. Thus  $h_1$  may be negative. In this case, the effect of diffraction by nearby terrain obstacles should be taken into account.

The procedure for negative values of  $h_1$  is to obtain the field strength for  $h_1 = 0$  as described in § 4.2, and to add a correction  $C_{h1}$  calculated as follows.

The effect of diffraction loss is taken into account by a correction,  $C_{h1}$ , given by cases a) or b) as follows:

- a) In the case that a terrain database is available and the potential for discontinuities at the transition around  $h_1 = 0$  is of no concern in the application of this Recommendation, the terrain clearance angle,  $\theta_{eff1}$ , from the transmitting/base antenna should be calculated as the elevation angle of a line which just clears all terrain obstructions up to 15 km from the transmitting/base antenna in the direction of (but not going beyond) the receiving/mobile antenna. This clearance angle, which will have a positive value, should be used instead of  $\theta_{ica}$  in equation (30c) in the terrain clearance angle correction method given in § 11 to obtain  $C_{h1}$ . Note that using this method can result in a discontinuity in field strength at the transition around  $h_1 = 0$ .
- b) In the case where a terrain database is not available or where a terrain database is available, but the method must never produce a discontinuity in the field strength at the transition around  $h_1 = 0$ , the (positive) effective terrain clearance angle,  $\theta_{eff2}$ , may be estimated assuming an obstruction of height  $h_1$  at a distance of 9 km from the transmitting/base antenna. Note that this is used for all path lengths, even when less than 9 km. That is, the ground is regarded as approximating an irregular wedge over the range 3 km to 15 km from the transmitting/base antenna, with its mean value occurring at 9 km, as indicated in Fig. 25. This method takes less explicit account of terrain variations, but it also guarantees that there is no discontinuity in field strength at the transition around  $h_1 = 0$ . The correction to be added to the field strength in this case is calculated using:

$$C_{h1} = 6.03 - J(v) \quad \text{dB} \quad (12)$$

where:

$$J(v) = \left[ 6.9 + 20 \log \left( \sqrt{(v-0.1)^2 + 1} + v - 0.1 \right) \right] \quad (12a)$$

$$v = K_v \theta_{eff2} \quad (12b)$$

and

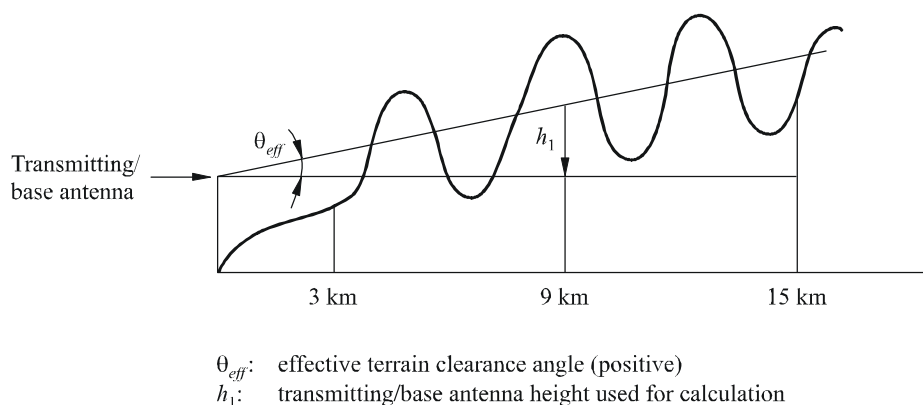
$$\theta_{eff2} = \arctan(-h_1 / 9\,000) \quad \text{degrees} \quad (12c)$$

$$K_v = 1.35 \quad \text{for 100 MHz}$$

$$K_v = 3.31 \quad \text{for 600 MHz}$$

$$K_v = 6.00 \quad \text{for 2 000 MHz}$$

FIGURE 25

Effective clearance angle for  $h_1 < 0$ 

1546-25

The above correction, which is always less than zero, is added to the field strength obtained for  $h_1 = 0$ .

## 5 Interpolation of field strength as a function of distance

Figures 1 to 24 show field strength plotted against distance,  $d$ , the range 1 km to 1 000 km. No interpolation for distance is needed if field strengths are read directly from these graphs. For greater precision, and for computer implementation, field strengths should be obtained from the associated tabulations (see Annex 1, § 3). In this case, unless  $d$  coincides with one of the tabulation distances given in Table 1, the field strength,  $E$  (dB( $\mu$ V/m)), should be linearly interpolated for the logarithm of the distance using:

$$E = E_{inf} + (E_{sup} - E_{inf}) \log(d / d_{inf}) / \log(d_{sup} / d_{inf}) \quad \text{dB}(\mu\text{V/m}) \quad (13)$$

where:

- $d$ : distance for which the prediction is required
- $d_{inf}$ : nearest tabulation distance less than  $d$
- $d_{sup}$ : nearest tabulation distance greater than  $d$
- $E_{inf}$ : field-strength value for  $d_{inf}$
- $E_{sup}$ : field-strength value for  $d_{sup}$ .

This Recommendation is not valid for values of  $d$  less than 1 km or greater than 1 000 km.

TABLE 1  
Values of distance used in the tables of field strengths (km)

1	14	55	140	375	700
2	15	60	150	400	725
3	16	65	160	425	750
4	17	70	170	450	775
5	18	75	180	475	800
6	19	80	190	500	825
7	20	85	200	525	850
8	25	90	225	550	875
9	30	95	250	575	900
10	35	100	275	600	925
11	40	110	300	625	950
12	45	120	325	650	975
13	50	130	350	675	1 000

## 6 Interpolation and extrapolation of field strength as a function of frequency

Field-strength values for the required frequency should be obtained by interpolating between the values for the nominal frequency values of 100, 600 and 2000 MHz. In the case of frequencies below 100 MHz or above 2000 MHz, the interpolation must be replaced by an extrapolation from the two nearer nominal frequency values. For most paths interpolation or extrapolation for log (frequency) can be used, but for some sea paths when the required frequency is less than 100 MHz it is necessary to use an alternative method.

For land paths, and for sea paths where the required frequency is greater than 100 MHz, the required field strength,  $E$ , should be calculated using:

$$E = E_{inf} + (E_{sup} - E_{inf}) \log(f / f_{inf}) / \log(f_{sup} / f_{inf}) \quad \text{dB}(\mu\text{V/m}) \quad (14)$$

where:

- $f$ : frequency for which the prediction is required (MHz)
- $f_{inf}$ : lower nominal frequency (100 MHz if  $f < 600$  MHz, 600 MHz otherwise)
- $f_{sup}$ : higher nominal frequency (600 MHz if  $f < 600$  MHz, 2000 MHz otherwise)
- $E_{inf}$ : field-strength value for  $f_{inf}$
- $E_{sup}$ : field-strength value for  $f_{sup}$ .

The field strength resulting from extrapolation for frequency above 2000 MHz should be limited if necessary such that it does not exceed the maximum value given in § 2.

For sea paths where the required frequency is less than 100 MHz an alternative method should be used, based upon the path lengths at which 0.6 of the first Fresnel zone is just clear of obstruction by the sea surface. An approximate method for calculating this distance is given in § 17.

The alternative method should be used if all of the following conditions are true:

- The path is a sea path.
- The required frequency is less than 100 MHz.
- The required distance is less than the distance at which a sea path would have 0.6 Fresnel clearance at 600 MHz, given by  $D_{06}(600, h_1, 10)$  as given in § 17.

If any of the above conditions is not true, then the normal interpolation/extrapolation method given by equation (14) should be used.

If all of the above conditions are true, the required field strength,  $E$ , should be calculated using:

$$E = E_{max} \quad \text{dB}(\mu\text{V/m}) \quad \text{for } d \leq d_f \quad (15a)$$

$$= E_{df} + (E_{d_{600}} - E_{df}) \log(d/d_f) / \log(d_{600}/d_f) \quad \text{dB}(\mu\text{V/m}) \quad \text{for } d > d_f \quad (15b)$$

where:

- $E_{max}$ : maximum field strength at the required distance as defined in § 2
- $E_{df}$ : maximum field strength at distance  $d_f$  as defined in § 2
- $d_{600}$ : distance at which the path has 0.6 Fresnel clearance at 600 MHz calculated as  $D_{06}(600, h_1, 10)$  as given in § 17
- $d_f$ : distance at which the path has 0.6 Fresnel clearance at the required frequency calculated as  $D_{06}(f, h_1, 10)$  as given in § 17
- $E_{d_{600}}$ : field strength at distance  $d_{600}$  and the required frequency calculated using equation (14).

## 7 Interpolation of field strength as a function of percentage time

Field-strength values for a given percentage of time between 1% and 50% time should be calculated by interpolation between the nominal values 1% and 10% or between the nominal values 10% and 50% of time using:

$$E = E_{sup} (Q_{inf} - Q_t) / (Q_{inf} - Q_{sup}) + E_{inf} (Q_t - Q_{sup}) / (Q_{inf} - Q_{sup}) \quad \text{dB}(\mu\text{V/m}) \quad (16)$$

where:

- $t$ : percentage time for which the prediction is required
- $t_{inf}$ : lower nominal percentage time
- $t_{sup}$ : upper nominal percentage time
- $Q_t = Q_i(t/100)$
- $Q_{inf} = Q_i(t_{inf}/100)$
- $Q_{sup} = Q_i(t_{sup}/100)$
- $E_{inf}$ : field-strength value for time percentage  $t_{inf}$
- $E_{sup}$ : field-strength value for time percentage  $t_{sup}$

where  $Q_i(x)$  is the inverse complementary cumulative normal distribution function.

This Recommendation is valid for field strengths exceeded for percentage times in the range 1% to 50% only. Extrapolation outside the range 1% to 50% time is not valid.

A method for the calculation of  $Q_i(x)$  is given in Annex 5, § 15.

## 8 Mixed paths

The following description of the mixed-path method uses  $E_{land}(d)$  and  $E_{sea}(d)$  to represent the field strength at distance  $d$  from the transmitting/mobile antenna at the representative clutter height,  $R$ , for all-land and all-sea paths respectively, with interpolation/extrapolation for transmitting/base antenna height  $h_1$ , frequency and percentage time, as required.

The following steps should be followed to determine the field strength of any path with a mixture of land and sea parts. If the path contains both warm sea and cold sea portions, the warm sea curves should be used when calculating  $E_{sea}(d)$ . The value of  $h_1$  should be calculated using Annex 5, § 3, taking the height of any sea surface as though land. Normally this value of  $h_1$  will be used for both  $E_{land}(d)$  and  $E_{sea}(d)$ . However, if  $h_1$  is less than 3 m it should still be used for  $E_{land}(d)$ , but a value of 3 m should be used for  $E_{sea}(d)$ .

The mixed path field strength,  $E$ , is given by:

$$E = (1 - A) \cdot E_{land}(d_{total}) + A \cdot E_{sea}(d_{total}) \quad (17)$$

with the mixed path interpolation factor,  $A$ , given in § 8.1.

*The following part up to the equation (21) is relevant to the propagation prediction method approved by the Regional Radiocommunication Conference RRC-06 only and not to this Recommendation.*

This guidance completes the discussion of the mixed path method employing the basic curves given in Annexes 2-4. In this case, continue with § 8.1. However, the coastal land type of the IDWM coastal zone area maps should not be interpreted as coastal land zones in the following context.

The mixed path method, given in equation (17), is general. It may also be applied to situations in which families of field-strength curves are defined for various propagation zones. (For example, different propagation zones might be specified by modifications to the basic field-strength curves, found in Annexes 2-4, using the method contained in Annex 8, or another, alternate, method of zonal specification, such as that found in the GE06 Agreement. These different zonal specifications may, possibly, include coastal land zones, however they are defined, as separate propagation zones, with propagation conditions that are more applicable to sea paths than land paths.) If, in addition, it is necessary to compute the field strength for a mixed path traversing two or more different propagation zones, then the following mixed path method is recommended:

- a) for all frequencies and all percentages of the time and for those combinations of propagation zone which do not involve any land/sea or land/coastal land transitions, the following procedure for calculating the field strength shall be used:

$$E = \sum_i \frac{d_i}{d_{total}} E_i(d_{total}) \quad (18)$$

where:

- $E$ : field strength for the mixed path (dB(μV/m))
- $E_i(d_{total})$ : field strength for path in zone  $i$  equal in length to the mixed path (dB(μV/m))
- $d_i$ : length of path in zone  $i$
- $d_{total}$ : length of total path;

- b) for all frequencies and all percentages of time and for those combinations of propagation zones which involve only a single land propagation category and a single sea or coastal land propagation category, equation (18) should be used;
- c) for all frequencies and all percentages of time and for those combinations of three or more propagation zones which involve at least one land/sea or land/coastal land boundary, the following procedure for calculating the field strength shall be used:

$$E = (1-A) \cdot \frac{\sum_{i=1}^{n_l} d_i E_{land,i}}{d_{lT}} + A \cdot \frac{\sum_{j=1}^{n_s} d_j E_{sea,j}}{d_{sT}} \quad (19)$$

where:

- $E$ : field strength for mixed path (dB(μV/m))
- $E_{land,i}$ : field strength for land path  $i$  equal in length to the mixed path,  $i = 1, \dots, n_l$ ;  $n_l$  is the number of land zones traversed (dB(μV/m))
- $E_{sea,j}$ : field strength for sea-and-coastal-land path  $j$  equal in length to the mixed path,  $j = 1, \dots, n_s$ ;  $n_s$  is the number of sea-and-coastal-land zones traversed (dB(μV/m))
- $A$ : interpolation factor as given in § 8.1 (note that the fraction of path over sea is calculated as:  $\frac{d_{sT}}{d_{total}}$ )
- $d_i, d_j$ : length of path in zones  $i, j$
- $d_{lT}$ : length of total land path =  $\sum_{i=1}^{n_l} d_i$
- $d_{sT}$ : length of total sea-and-coastal-land path =  $\sum_{j=1}^{n_s} d_j$
- $d_{total}$ : length of total propagation path =  $d_{lT} + d_{sT}$ .

### 8.1 The mixed path interpolation factor, $A$

The following notation will be used:

- $N_s$ : total number of sea zones and coastal land zones
- $n$ : sea-path or coastal land-path zone number;  $n = 1, 2, \dots, N_s$
- $M_l$ : total number of land zones
- $m$ : land-path zone number;  $m = 1, 2, \dots, M_l$
- $d_{sn}$ : distance traversed in sea or coastal land zone  $n$  (km)
- $d_{lm}$ : distance traversed in land zone  $m$  (km).

Then:

$$d_{sT} = \sum_{n=1}^{N_s} d_{sn} : \quad \text{total length of sea and coastal land paths traversed} \quad (20a)$$

$$d_{lT} = \sum_{m=1}^{M_l} d_{lm} : \quad \text{total length of land paths traversed} \quad (20b)$$

$$d_T = d_{sT} + d_{lT} : \quad \text{length of the total propagation path.} \quad (20c)$$

The following field-strength values are needed:

$E_{sn}(d_T)$ : field-strength value (dB(μV/m)) for distance  $d_T$ , assumed to be all of sea or coastal-land zone type  $n$

$E_{lm}(d_T)$ : field-strength value (dB(μV/m)) for distance  $d_T$ , assumed to be all of land zone type  $m$ .

*End of the part relevant to the propagation prediction method approved by the Regional Radiocommunication Conference RRC-06 only.*

The interpolation factor<sup>1</sup>,  $A$ , is given by:

$$A = A_0 (F_{sea})^V \quad (21)$$

where  $A_0(F_{sea})$  is the basic interpolation factor as shown in Fig. 26, given by:

$$A_0(F_{sea}) = 1 - (1 - F_{sea})^{2/3} \quad (22)$$

The fraction of path over sea,  $F_{sea}$ , used in Fig. 26 and equation (22) is given by:

$$F_{sea} = \frac{d_{sT}}{d_T} \quad (23)$$

and  $V$  is calculated using the expression:

$$V = \max \left[ 1.0, 1.0 + \frac{\Delta}{40.0} \right] \quad (24)$$

with:

$$\Delta = \sum_{n=1}^{N_s} E_{sn}(d_T) \frac{d_{sn}}{d_{sT}} - \sum_{m=1}^{M_l} E_{lm}(d_T) \frac{d_{lm}}{d_{lT}} \quad (25)$$

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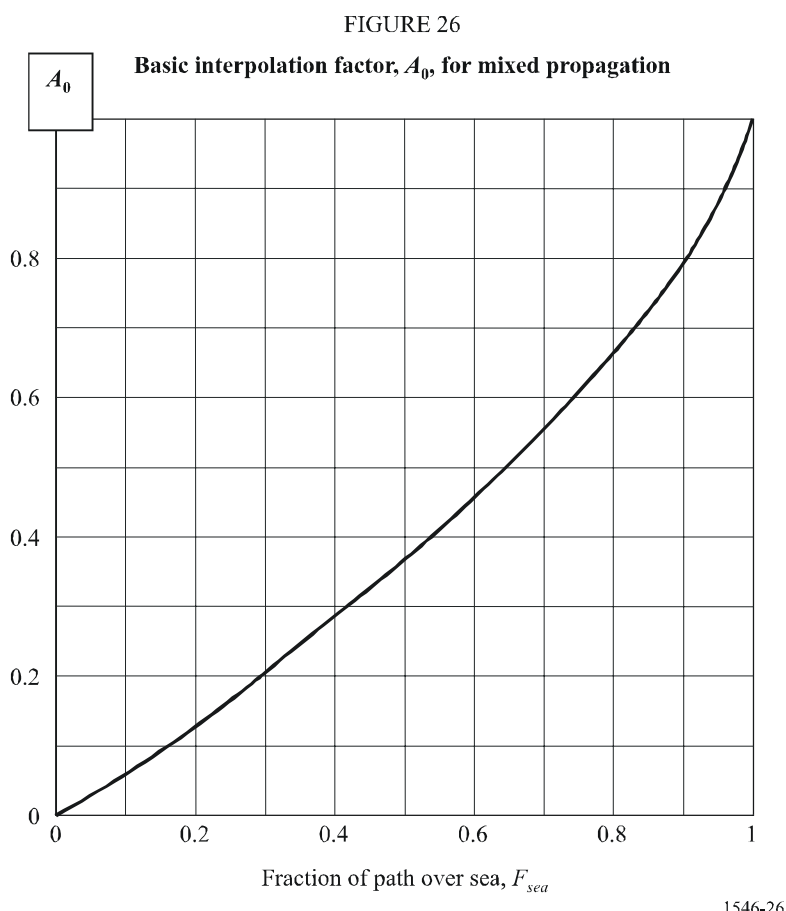
<sup>1</sup> The interpolation factor is applied to all frequencies and to all time percentages. It must be noted that the interpolation is only applied to:

- land-sea paths
- land-coastal land paths
- land-(sea + coastal land) paths

and not to:

- land-land paths
- or any combination of sea and/or coastal-land paths.

Figure 26 shows  $A_0(F_{sea})$ , which is applicable for all time percentages.



## 9 Correction for receiving/mobile antenna height

The field-strength values given by the land curves and associated tabulations in this Recommendation are for a reference receiving/mobile antenna at a height,  $R$  (m), representative of the height of the ground cover surrounding the receiving/mobile antenna, subject to a minimum height value of 10 m. Examples of reference heights are 20 m for an urban area, 30 m for a dense urban area and 10 m for a suburban area. For sea paths the notional value of  $R$  is 10 m.

Where the receiving/mobile antenna is on land account should first be taken of the elevation angle of the arriving ray by calculating a modified representative clutter height  $R'$  (m), given by:

$$R' = (1000dR - 15h_1) / (1000d - 15) \quad \text{m} \quad (26)$$

where  $h_1$  and  $R$  (m) and distance  $d$  (km).

Note that for  $h_1 < 6.5d + R$ ,  $R' \approx R$ .

The value of  $R'$  must be limited if necessary such that it is not less than 1 m.

When the receiving/mobile antenna is in an urban environment the correction is then given by:

$$\text{Correction} = 6.03 - J(v) \quad \text{dB} \quad \text{for } h_2 < R' \quad (27a)$$

$$= K_{h_2} \log(h_2 / R') \quad \text{dB} \quad \text{for } h_2 \geq R' \quad (27b)$$

where  $J(v)$  is given by equation (12a),

and:

$$v = K_{nu} \sqrt{h_{dif} \theta_{clut}} \quad (27c)$$

$$h_{dif} = R' - h_2 \quad \text{m} \quad (27d)$$

$$\theta_{clut} = \arctan(h_{dif} / 27) \quad \text{degrees} \quad (27e)$$

$$K_{h2} = 3.2 + 6.2 \log(f) \quad (27f)$$

$$K_{nu} = 0.0108 \sqrt{f} \quad (27g)$$

$f$ : frequency (MHz).

In cases in an urban environment where  $R'$  is less than 10 m, the correction given by equation (27) should be reduced by  $K_{h2} \log(10/R')$ .

Where the receiving/mobile antenna is on land in a rural or open environment the correction is given by equation (27b) for all values of  $h_2$  with  $R'$  set to 10 m.

In the following, the expression “adjacent to sea” applies to cases where the receiving/mobile antenna is either over sea, or is immediately adjacent to the sea with no significant obstruction in the direction of the transmitting/base station.

Where the receiving/mobile antenna is adjacent to sea for  $h_2 \geq 10$  m, the correction should be calculated using equation (27b) with  $R'$  set to 10 m.

Where the receiving/mobile antenna is adjacent to sea for  $h_2 < 10$  m, an alternative method should be used, based upon the path lengths at which 0.6 of the first Fresnel zone is just clear of obstruction by the sea surface. An approximate method for calculating this distance is given in § 17.

The distance at which the path would just have 0.6 Fresnel clearance for the required value of  $h_1$  and for  $h_2 = 10$  m,  $d_{10}$ , should be calculated as  $D_{06}(f, h_1, 10)$  in § 17.

If the required distance is equal to or greater than  $d_{10}$ , then again the correction for the required value of  $h_2$  should be calculated using equation (27b) with  $R'$  set to 10 m.

If the required distance is less than  $d_{10}$ , then the correction to be added to the field strength  $E$  should be calculated using:

$$\text{Correction} = 0.0 \quad \text{dB} \quad \text{for} \quad d \leq d_{h2} \quad (28a)$$

$$= C_{10} \log(d/d_{h2}) / \log(d_{10}/d_{h2}) \quad \text{dB} \quad \text{for} \quad d_{h2} < d < d_{10} \quad (28b)$$

where:

$C_{10}$ : correction for the required value of  $h_2$  at distance  $d_{10}$  using equation (27b) with  $R'$  set to 10 m

$d_{10}$ : distance at which the path just has 0.6 Fresnel clearance for  $h_2 = 10$  m calculated as  $D_{06}(f, h_1, 10)$  as given in § 17

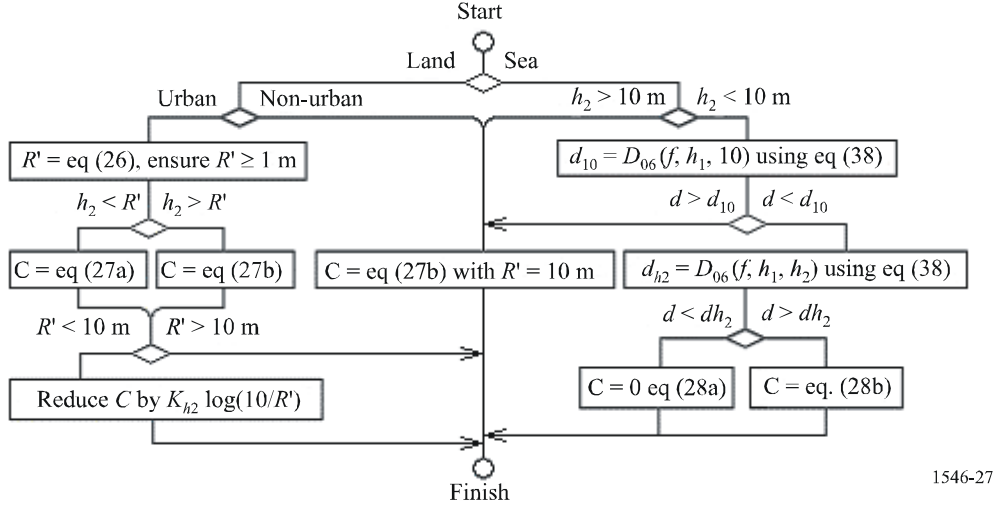
$d_{h2}$ : distance at which the path just has 0.6 Fresnel clearance for the required value of  $h_2$  calculated as  $D_{06}(f, h_1, 10)$  as given in § 17.

This Recommendation is not valid for receiving/mobile antenna heights,  $h_2$ , less than 1 m when adjacent to land or less than 3 m when adjacent to sea.

The above complete correction for receiver/mobile antenna height can be summarized by the flowchart given in Fig. 27.

FIGURE 27

Flow chart for receiver/mobile antenna height correction



1546-27

## 10 Correction for short urban/suburban paths

If a path of length less than 15 km covers buildings of uniform height over flat terrain, a correction representing the reduction of field strength due to building clutter should be added to the field strength. The correction is given by:

$$\text{Correction} = -3.3(\log(f))(1 - 0.85\log(d))(1 - 0.46\log(1 + h_a - R)) \quad (29)$$

where  $h_a$  is the antenna height above ground (m) (i.e. height of the mast) and  $R$  is representative of the height of the ground cover surrounding the receiving/mobile antenna as defined in § 9, which also represents the height of ground cover surrounding the transmitting/base antenna. This correction only applies when  $d$  is less than 15 km and  $h_1 - R$  is less than 150 m.

## 11 Terrain clearance angle correction

For land paths, and when the receiving/mobile antenna is on a land section of a mixed path, if more precision is required for predicting the field strength for reception conditions in specific areas, e.g. in a small reception area, a correction may be made based on a terrain clearance angle. The terrain clearance angle  $\theta_{tca}$  is given by:

$$\theta_{tca} = \theta \quad \text{degrees} \quad (30)$$

where  $\theta$  is the elevation angle of the line from the receiving/mobile antenna which just clears all terrain obstructions in the direction of the transmitter/base antenna over a distance of up to 16 km but not going beyond the transmitting/base antenna.

The calculation of  $\theta$  should not take Earth curvature into account.  $\theta_{tca}$  should be limited such that it is not less than  $+0.55^\circ$  or more than  $+40.0^\circ$ .

Where the relevant terrain clearance angle information is available, the correction to be added to the field strength is calculated using:

$$\text{Correction} = J(v') - J(v) \quad \text{dB} \quad (30a)$$

where  $J(v)$  is given by equation (12a):

$$v' = 0.036\sqrt{f} \quad (30b)$$

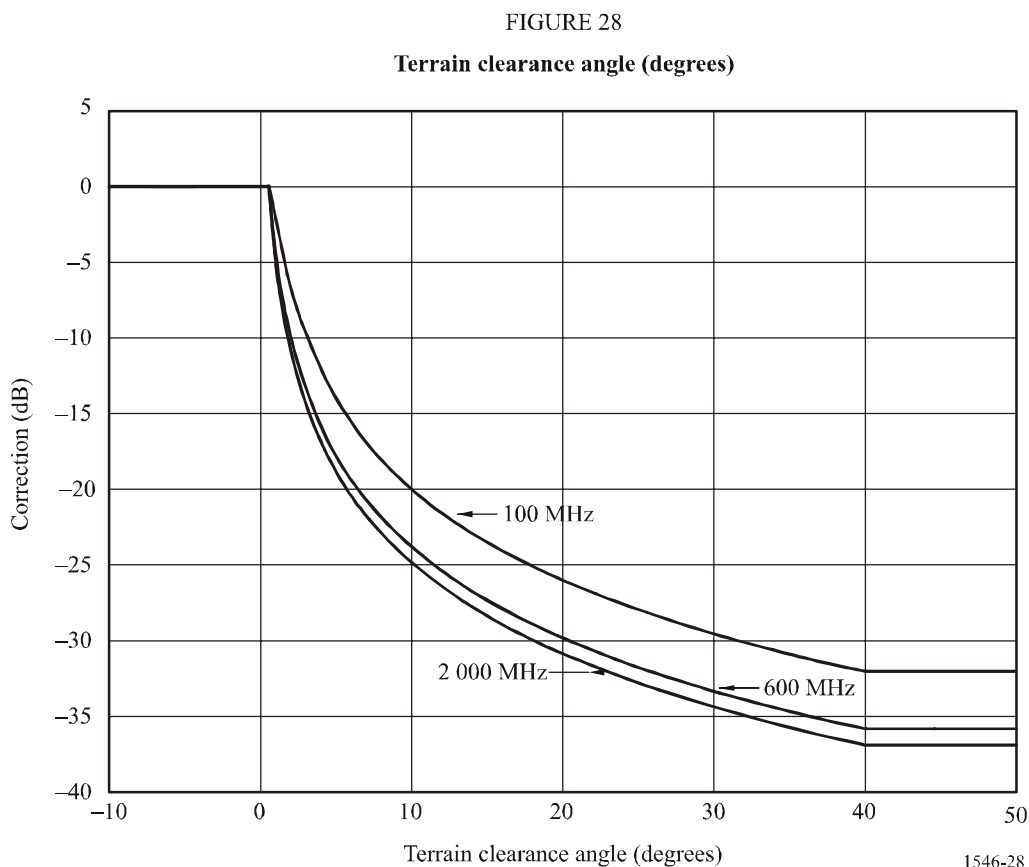
$$v = 0.065 \theta_{ica} \sqrt{f} \quad (30c)$$

$\theta_{ica}$ : terrain clearance angle (degrees)

$f$ : required frequency (MHz).

It should be noted that the land field-strength curves take account of losses due to typical shielding of the receiving/mobile antenna by gently rolling terrain. Thus the terrain clearance angle corrections are zero at a small positive angle typical of receiving/mobile antenna positions.

Figure 28 illustrates the terrain clearance angle correction for the nominal frequencies.



## 12 Location variability in land area-coverage prediction

Area-coverage prediction methods are intended to provide the statistics of reception conditions over a given area, rather than at any particular point. The interpretation of such statistics will depend on the size of the area considered.

When one terminal of a radio path is stationary, and the other terminal is moved, path loss will vary continuously with location, according to the totality of influences affecting it. It is convenient to classify these influences into three main categories:

*Multipath variations:* Signal variations will occur over scales of the order of a wavelength due to phasor addition of multipath effects, e.g. reflections from the ground, buildings, etc. The statistics of these variations are typically found to follow the Rayleigh distribution.

*Local ground cover variations:* Signal variations will occur due to obstruction by ground cover in the local vicinity, e.g. buildings, trees, etc., over scales of the order of the sizes of such objects. The scale of these variations will normally be significantly larger than that for multipath variations.

*Path variations:* Signal variations will also occur due to changes in the geometry of the entire propagation path e.g. the presence of hills, etc. For all except very short paths, the scale of these variations will be significantly larger than that for local ground cover variations.

In this Recommendation, and generally, location variability refers to the spatial statistics of local ground cover variations. This is a useful result over scales substantially larger than the ground cover variations, and over which path variations are insignificant. As location variability is defined to exclude multipath variations, it is not dependent on system bandwidth.

In the planning of radio systems, it will also be necessary to take multipath effects into account. The impact of these effects will vary with systems, being dependent on bandwidth, modulation and coding scheme. Guidance on the modelling of these effects is given in Recommendation ITU-R P.1406.

Location variability has been variously defined. Some texts define it as relating to the variation in excess path loss over the entire service area of a transmitter, thus including all terrain effects, in addition to more local shadowing. In other cases, it relates to the variation in path loss for all points at a given radius from the transmitter. A third definition relates to the variability of field strength over a small area, typically represented by a square with a side of 500 m to 1 km.

As the prediction method given in this Recommendation includes an environment-dependent correction for  $h_2$  (Annex 5, § 9) and allows the use of terrain-dependant TCA (Annex 5, § 11) there is a risk of double-counting of these effects in applying corrections for location variability.

The method below estimates the location variability over a small area, and is appropriate for cases where TCA is applied to allow the more accurate determination of local median field strengths.

Where TCA is not applied, the appropriate value of location variability will be greater, and will generally scale with service area radius, as a wider variety of terrain and clutter are included.

Extensive data analysis suggests that the distribution of median field strength due to ground cover variations over such an area in urban and suburban environments is approximately lognormal.

Thus for a land receiving/mobile antenna location the field strength,  $E$ , which will be exceeded for  $q\%$  of locations is given by:

$$E(q) = E(\text{median}) + Q_i(q/100)\sigma_L(f) \quad \text{dB}(\mu\text{V/m}) \quad (31)$$

where:

$Q_i(x)$ : inverse complementary cumulative normal distribution as a function of probability

$\sigma_L$ : standard deviation of the Gaussian distribution of the local means in the study area.

Values of standard deviation are dependent on frequency and environment, and empirical studies have shown a considerable spread. Representative values for areas of 500 m × 500 m are given by the following expression:

$$\sigma_L = K + 1.3 \log(f) \quad \text{dB} \quad (32)$$

where:

$K = 1.2$ , for receivers with antennas below clutter height in urban or suburban environments for mobile systems with omnidirectional antennas at car-roof height

$K = 1.0$ , for receivers with rooftop antennas near the clutter height

$K = 0.5$ , for receivers in rural areas

$f$ : required frequency (MHz).

As noted above, if the area over which the variability is to apply is greater than 500 m × 500 m, or if the variability is to relate to all areas at a given range, rather than the variation across individual areas, the value of  $\sigma_L$  will be greater. Empirical studies have suggested that location variability is increased (with respect to the small area values) by up to 4 dB for a 2 km radius and up to 8 dB for a 50 km radius.

Percentage location  $q$  can vary between 1 and 99. This Recommendation is not valid for percentage locations less than 1% or greater than 99%.

The location variability correction is not applied when the receiver/mobile is adjacent to sea.

It should be noted that, for some planning purposes (e.g. multilateral allotment plans) it will generally be necessary to use a definition of “location variability” that includes a degree of multipath fading. This will allow for the case of a mobile receiver, stationary in a multipath null, or for a rooftop antenna where a number of frequencies are to be received and the antenna cannot be optimally positioned for all. Additionally, such planning may also need to consider variability over a greater area than that assumed in this Recommendation.

In this context, the values given in Table 2 have been found appropriate for the planning of a number of radio services.

TABLE 2  
Values of variability used in certain planning situations

	Standard deviation (dB)		
	100 MHz	600 MHz	2 000 MHz
Broadcasting, analogue	8.3	9.5	–
Broadcasting, digital	5.5	5.5	5.5

### 13 Correction based on tropospheric scattering

There is a possibility that the field strength calculated using the methods given in § 1 to 12 of this Annex is an underestimation, due to not taking full account of tropospheric scattering.

If terrain information is available, a correction for tropospheric scattering should be calculated using the following procedure.

Calculate the path scattering angle in degrees,  $\theta_s$ , using:

$$\theta_s = \frac{180d}{\pi ka} + \theta_{eff} + \theta \quad \text{degrees} \quad (33)$$

where:

- $\theta_{eff}$ : the  $h_1$  terminal's terrain clearance angle in degrees calculated using the method in § 4.3 case a), whether or not  $h_1$  is negative (degrees)
- $\theta$ : the  $h_2$  terminal's clearance angle in degrees as calculated in § 11, noting that this is the elevation angle relative to the local horizontal (degrees)
- $d$ : path length (km)
- $a$ : 6 370 km, radius of the Earth
- $k$ : 4/3, effective Earth radius factor for median refractivity conditions.

If  $\theta_s$  is less than zero, set  $\theta_s$  equal to zero.

Calculate the field strength predicted for tropospheric scattering,  $E_{ts}$ , using:

$$E_{ts} = 24.4 - 20 \log(d) - 10 \theta_s - L_f + 0.15 N_0 + G_t \quad \text{dB}(\mu\text{V/m}) \quad (34)$$

where:

$$\begin{aligned} L_f: & \text{ frequency-dependent loss} \\ & = 5 \log(f) - 2.5(\log(f) - 3.3)^2 \end{aligned} \quad (34a)$$

$N_0$  = 325, median surface refractivity,  $N$ -units, typical of temperate climates

$$\begin{aligned} G_t: & \text{ time-dependent enhancement} \\ & = 10.1(-\log(0.02t))^{0.7} \end{aligned} \quad (34b)$$

$d$ : path length or required distance (km)

$f$ : required frequency (MHz)

$t$ : required percentage of time.

#### 14 Field-strength predictions for distances less than 1 km

If this Recommendation is used where values of  $d$  less than 1 km may occur and where the of a short-range propagation model is not practicable and a simple means is required to converge towards free-space field strengths for arbitrarily short distances (recognizing that this is purely a convenience, not a valid propagation model), the following procedure can be used.

Estimate the field strength,  $E$ , at a distance less than 1 km using:

$$E = E_{max\ nf} \quad \text{dB}(\mu\text{V/m}) \quad \text{for} \quad d \leq d_{nf} \quad (35a)$$

$$E = E_{max\ d} \quad \text{dB}(\mu\text{V/m}) \quad \text{for} \quad d_{nf} < d \leq 0.1 \text{ km} \quad (35b)$$

$$E_{0.1 \text{ km}} + (E_{1 \text{ km}} - E_{0.1 \text{ km}}) \log(d / 0.1) \quad \text{dB}(\mu\text{V/m}) \quad \text{for} \quad 0.1 \text{ km} < d < 1.0 \text{ km} \quad (35c)$$

where:

$E_{max\ nf}$ : maximum field strength at a distance of  $d_{nf}$  km given by equations (1a) or (1b)

$E_{max\ d}$ : maximum field strength at the required distance given by equations (1a) or (1b)

$E_{0.1 \text{ km}}$  : maximum field strength at a distance of 0.1 km given by equations (1a) or (1b)

$E_{1 \text{ km}}$  : field strength at a distance of 1 km,

and  $d_{nf}$  is an estimate of the near-field distance of the transmitting/base antenna given by:

$$d_{nf} = 10^{0.1G} / (10f) \quad \text{km} \quad (35d)$$

where:

$G$ : antenna gain (dBi)

$f$ : frequency (MHz).

The value of  $d_{nf}$  should be limited such that  $d_{nf} \leq 0.1 \text{ km}$ .

A default value of  $d_{nf} = 0.01 \text{ km}$  is suggested.

The corrections relating to the receiver/mobile remain valid. If used, they should be applied for the actual location of the receiver/mobile, not at 1 km from the transmitter/base station.

## 15 An approximation to the inverse complementary cumulative normal distribution function

The following approximation to the inverse complementary cumulative normal distribution function,  $Q_i(x)$ , is valid for  $0.01 \leq x \leq 0.99$ :

$$Q_i(x) = T(x) - \xi(x) \quad \text{if } x \leq 0.5 \quad (36a)$$

$$Q_i(x) = -\{T(1-x) - \xi(1-x)\} \quad \text{if } x > 0.5 \quad (36b)$$

where:

$$T(x) = \sqrt{[-2 \ln(x)]} \quad (36c)$$

$$\xi(x) = \frac{[(C_2 \cdot T(x) + C_1) \cdot T(x)] + C_0}{[(D_3 \cdot T(x) + D_2) \cdot T(x) + D_1] \cdot T(x) + 1} \quad (36d)$$

$$C_0 = 2.515517$$

$$C_1 = 0.802853$$

$$C_2 = 0.010328$$

$$D_1 = 1.432788$$

$$D_2 = 0.189269$$

$$D_3 = 0.001308$$

Values given by the above equations are given in Table 3.

TABLE 3  
Approximate inverse complementary cumulative  
normal distribution values

$q\%$	$Q_i(q/100)$	$q\%$	$Q_i(q/100)$	$q\%$	$Q_i(q/100)$	$q\%$	$Q_i(q/100)$
1	2.327	26	0.643	51	-0.025	76	-0.706
2	2.054	27	0.612	52	-0.050	77	-0.739
3	1.881	28	0.582	53	-0.075	78	-0.772
4	1.751	29	0.553	54	-0.100	79	-0.806
5	1.645	30	0.524	55	-0.125	80	-0.841
6	1.555	31	0.495	56	-0.151	81	-0.878
7	1.476	32	0.467	57	-0.176	82	-0.915
8	1.405	33	0.439	58	-0.202	83	-0.954
9	1.341	34	0.412	59	-0.227	84	-0.994
10	1.282	35	0.385	60	-0.253	85	-1.036
11	1.227	36	0.358	61	-0.279	86	-1.080
12	1.175	37	0.331	62	-0.305	87	-1.126
13	1.126	38	0.305	63	-0.331	88	-1.175
14	1.080	39	0.279	64	-0.358	89	-1.227
15	1.036	40	0.253	65	-0.385	90	-1.282
16	0.994	41	0.227	66	-0.412	91	-1.341
17	0.954	42	0.202	67	-0.439	92	-1.405
18	0.915	43	0.176	68	-0.467	93	-1.476
19	0.878	44	0.151	69	-0.495	94	-1.555
20	0.841	45	0.125	70	-0.524	95	-1.645
21	0.806	46	0.100	71	-0.553	96	-1.751
22	0.772	47	0.075	72	-0.582	97	-1.881
23	0.739	48	0.050	73	-0.612	98	-2.054
24	0.706	49	0.025	74	-0.643	99	-2.327
25	0.674	50	0.000	75	-0.674		

## 16 Equivalent basic transmission loss

When required, the basic transmission loss equivalent to a given field strength is given by:

$$L_b = 139.3 - E + 20 \log f \quad \text{dB} \quad (37)$$

where:

$L_b$ : basic transmission loss (dB)

$E$ : field strength (dB( $\mu\text{V/m}$ )) for 1 kW e.r.p.

$f$ : frequency (MHz).

### 17 An approximation to the 0.6 Fresnel clearance path length

The path length which just achieves a clearance of 0.6 of the first Fresnel zone over a smooth curved Earth, for a given frequency and antenna heights  $h_1$  and  $h_2$ , is given approximately by:

$$D_{06} = \frac{D_f \cdot D_h}{D_f + D_h} \quad \text{km} \quad (38)$$

where:

$$\begin{aligned} D_f: & \text{ frequency-dependent term} \\ & = 0.0000389 f h_1 h_2 \quad \text{km} \end{aligned} \quad (39a)$$

$$\begin{aligned} D_h: & \text{ asymptotic term defined by horizon distances} \\ & = 4.1(\sqrt{h_1} + \sqrt{h_2}) \quad \text{km} \end{aligned} \quad (39b)$$

$f$ : frequency (MHz)

$h_1, h_2$ : antenna heights above smooth Earth (m).

In the above equations, the value of  $h_1$  must be limited, if necessary, such that it is not less than zero. Moreover, the resulting values of  $D_{06}$  must be limited, if necessary, such that it is not less than 0.001 km.

## Annex 6

### Procedure for the application of this Recommendation

The step-by-step procedure given below is intended to be applied to values derived from the field strength versus distance tables available from the Radiocommunication Bureau. They may, however, also be applied to values obtained from the curves in which case the distance interpolation procedure of Step 8.1.5 is not needed. Table 4 below contains a minimal list of input parameters (and their limits) that would serve as the basis for deriving values from the field strength versus distance tables. The step-by-step procedure follows.

TABLE 4  
List of input parameters and their limits

Parameter	Units	Definition	Limits
$f$	MHz	Operating frequency	30-3 000 MHz
$d$	km	Path length	1-1 000 km
$p$	%	Percentage time. Defined in Annex 1, § 8	1-50%
$h_1$	m	Transmitting/base antenna height as referenced in curves. Defined by Annex 5, § 3, equations (4) to (7) Limits are defined in § 4.1	Land – No lower limit, upper limit of 3 000 m Sea – Not less than 1 m, upper limit of 3 000 m
$h_a$	m	Transmitter antenna height above ground. Defined in Annex 5, § 3.1.1. Limits are defined in Annex 5, § 3	Must be greater than local clutter height
$h_b$	m	Height of base antenna above terrain height averaged 0.2 $d$ and $d$ km, where $d$ is less than 15 km and where terrain information is available	None – But note this parameter only exists for land paths where $d < 15$ km
Clutter height surrounding transmitter	m	Representative clutter height (around transmitter)	None
$R$	m	Representative clutter height (around receiver)	None
$\theta_{tca}$	degrees	Terrain clearance angle	0.55-40 degrees
$\theta_{eff}$ $\theta_{eff1}$ $\theta_{eff2}$	degrees	Transmitter/base effective terrain clearance angles. Annex 5, § 9	Must be positive

*Step 1:* Determine the type of the propagation path as land, cold sea or warm sea. If the path is mixed then determine two path types which are regarded as first and second propagation types. If the path can be represented by a single type then this is regarded as the first propagation type and the mixed-path method given in Step 11 is not required.

*Step 2:* For any given percentage of time (in the range 1% to 50% time) determine two nominal time percentages as follows:

- wanted time percentage  $> 1$  and  $< 10$ , the lower and higher nominal percentages are 1 and 10, respectively;
- wanted time percentage  $> 10$  and  $< 50$ , the lower and higher nominal percentages are 10 and 50, respectively.

If the required percentage of time is equal to 1% or 10% or 50%, this value should be regarded as the lower nominal percentage time and the interpolation process of Step 10 is not required.

*Step 3:* For any wanted frequency (in the range 30 to 3 000 MHz) determine two nominal frequencies as follows:

- where the wanted frequency  $< 600$  MHz, the lower and higher nominal frequencies are 100 and 600 MHz, respectively;
- where the wanted frequency  $> 600$  MHz, the lower and higher nominal frequencies are 600 and 2 000 MHz, respectively.

If the wanted frequency equals 100 or 600 or 2 000 MHz, this value should be regarded as the lower nominal frequency and the interpolation/extrapolation process of Step 9 is not required.

*Step 4:* Determine the lower and higher nominal distances from Table 1 closest to the required distance. If the required distance coincides with a value in Table 1, this should be regarded as the lower nominal distance and the interpolation process of Step 8.1.5 is not required.

*Step 5:* For the first propagation type follow Steps 6 to 11.

*Step 6:* For the lower nominal percentage time follow Steps 7 to 10.

*Step 7:* For the lower nominal frequency follow Steps 8 and 9.

*Step 8:* Obtain the field strength exceeded at 50% locations for a receiving/mobile antenna at the height of representative clutter,  $R$ , above ground for the required distance and transmitting/base antenna height as follows:

*Step 8.1:* For a transmitting/base antenna height  $h_1$  equal to or greater than 10 m follow Steps 8.1.1 to 8.1.6:

*Step 8.1.1:* Determine the lower and higher nominal  $h_1$  values using the method given in Annex 5, § 4.1. If  $h_1$  coincides with one of the nominal values 10, 20, 37.5, 75, 150, 300, 600 or 1200 m, this should be regarded as the lower nominal value of  $h_1$  and the interpolation process of Step 8.1.6 is not required.

*Step 8.1.2:* For the lower nominal value of  $h_1$  follow Steps 8.1.3 to 8.1.5.

*Step 8.1.3:* For the lower nominal value of distance follow Step 8.1.4.

*Step 8.1.4:* Obtain the field strength exceeded at 50% locations for a receiving/mobile antenna at the height of representative clutter,  $R$ , for the required values of distance,  $d$ , and transmitting/base antenna height,  $h_1$ .

*Step 8.1.5:* If the required distance does not coincide with the lower nominal distance, repeat Step 8.1.4 for the higher nominal distance and interpolate the two field strengths for distance using the method given in Annex 5, § 5.

*Step 8.1.6:* If the required transmitting/base antenna height,  $h_1$ , does not coincide with one of the nominal values, repeat Steps 8.1.3 to 8.1.5 and interpolate/extrapolate for  $h_1$  using the method given in Annex 5, § 4.1. If necessary limit the result to the maximum given in Annex 5, § 2.

*Step 8.2:* For a transmitting/base antenna height  $h_1$  less than 10 m determine the field strength for the required height and distance using the method given in Annex 5, § 4.2. If  $h_1$  is less than zero, the method given in Annex 5, § 4.3 should also be used.

*Step 9:* If the required frequency does not coincide with the lower nominal frequency, repeat Step 8 for the higher nominal frequency and interpolate or extrapolate the two field strengths using the method given in Annex 5, § 6. If necessary limit the result to the maximum field strength as given in Annex 5, § 2.

*Step 10:* If the required percentage time does not coincide with the lower nominal percentage time, repeat Steps 7 to 9 for the higher nominal percentage time and interpolate the two field strengths using the method given in Annex 5, § 7.

*Step 11:* If the prediction is for a mixed path, follow the step-by-step procedure given in Annex 5, § 8. This requires use of Steps 6 to 10 for paths of each propagation type. Note that if different sections of the path exist classified as both cold and warm sea, all sea sections should be classified as warm sea.

*Step 12:* If information on the terrain clearance angle at a receiving/mobile antenna adjacent to land is available, correct the field strength for terrain clearance angle at the receiver/mobile using the method given in Annex 5, § 11.

*Step 13:* Calculate the estimated field strength due to tropospheric scattering using the method given in Annex 5 § 13, and, if necessary, adjust the final predicted field strength accordingly.

*Step 14:* Correct the field strength for receiving/mobile antenna height  $h_2$  using the method given in Annex 5, § 9.

*Step 15:* If applicable, reduce the field strength by adding the correction for short urban/suburban paths using the method given in Annex 5, § 10.

*Step 16:* If the field strength at a receiving/mobile antenna adjacent to land exceeded at percentage locations other than 50% is required, correct the field strength for the required percentage of locations using the method given in Annex 5, § 12.

*Step 17:* If necessary, limit the resulting field strength to the maximum given in Annex 5, § 2. If a mixed path calculation has been made for a percentage time less than 50% it will be necessary to calculate the maximum field strength by linear interpolation between the all-land and all-sea values. This is given by:

$$E_{max} = E_{fs} + d_s E_{se} / d_{total} \quad \text{dB}(\mu\text{V/m}) \quad (40)$$

where:

$E_{fs}$ : free-space field strength given by equation (2) in Annex 5, § 2

$E_{se}$ : enhancement at small time percentages for a sea path given by equation (3) in Annex 5, § 2

$d_s$ : the total sea distance (km)

$d_{total}$ : the total path distance (km).

*Step 18:* If required, convert field strength to equivalent basic transmission loss for the path using the method given in Annex 5, § 16.

## Annex 7

### Comparison with the Okumura-Hata method

The Okumura-Hata method is given by:

$$E = 69.82 - 6.16 \log f + 13.82 \log H_1 + a(H_2) - (44.9 - 6.55 \log H_1)(\log d)^b \quad (41)$$

where:

$E$ : field strength (dB( $\mu\text{V/m}$ )) for 1 kW e.r.p.

$f$ : frequency (MHz)

$H_1$ : base station effective antenna height above ground (m) in the range 30 to 200 m

$H_2$ : mobile station antenna height above ground (m) in the range 1 to 10 m

$d$ : distance (km)

$$a(H_2) = (1.1 \log f - 0.7) H_2 - (1.56 \log f - 0.8)$$

$$b = 1 \text{ for } d \leq 20 \text{ km}$$

$$b = 1 + (0.14 + 0.000187 f + 0.00107 H_1') (\log [0.05 d])^{0.8} \quad \text{for } d > 20 \text{ km}$$

where:

$$H'_1 = H_1 / \sqrt{1 + 0.000007 H_1^2}$$

This Recommendation produces similar results to the Okumura-Hata method for distances up to 10 km,  $h_2 = H_2 = 1.5$  m,  $R = 15$ .

## Annex 8

### Adjustment for different climatic regions

The curves given in Annexes 2, 3 and 4 are based on measurements in temperate climates. Field strengths in regions of the world where the vertical atmospheric refractivity gradient is significantly different will not, in general, be so accurately predicted.

The following method may be used to apply vertical refractivity gradient information from Recommendation ITU-R P.453 to correct the curves in Annexes 2, 3 and 4 for use anywhere in the world. The Recommendation ITU-R P.453 data files give refractivity gradients in  $N$ -units/km in the lowest 65 m of the atmosphere as negative values.

For the purpose of this adjustment the curves in Annexes 2, 3 and 4 are considered to represent reference values of gradient  $dN_0$  given by:

$$\text{For fields exceeded for 50\% time: } dN_0 = -43.3 \quad N\text{-units/km} \quad (42a)$$

$$\text{For fields exceeded for 10\% time: } dN_0 = -141.9 \quad N\text{-units/km} \quad (42b)$$

$$\text{For fields exceeded for 1\% time: } dN_0 = -301.3 \quad N\text{-units/km} \quad (42c)$$

To adjust a family of field-strength curves for a different radio-climatic region of the world, calculate the difference in gradient  $\Delta N$  given by:

$$\Delta N = dN_0 - dN \quad (43)$$

where:

$dN$ : gradient exceeded for the time percentage of the curves to be adjusted obtained from the Recommendation ITU-R P.453 data files DNDZ\_50.TXT, DNDZ\_10.TXT, DNDZ\_01.TXT for 50%, 10% and 1% time, respectively.

$dN_0$ : reference gradient for the percentage time of the curve to be adjusted given by equations (40).

For any distance,  $d$  (km), if  $dN$  is less than  $-301.3$ , add an adjustment to the maximum field strength given by:

$$\delta E_{\max} = 0.007(-301.3 - dN) \{1 - \exp(-d/50)\} \exp(-d/6\,000) \quad \text{dB} \quad (44)$$

Note that no change is made to maximum field strengths if  $dN$  is greater than or equal to  $-301.3$ .

Calculate the scaling factor  $K$  given by:

$$K = 14.94 - 6.693 \times 10^{-6} (1\,494 - \Delta N)^2 \quad \Delta N > 0 \quad (45a)$$

$$= 0.08 \Delta N \quad \Delta N \leq 0 \quad (45b)$$

For the lowest curve in the family to be adjusted, that is for  $h_1 = 10$  m, add an adjustment,  $\delta E_1$ , given by:

$$\delta E_1 = K \{1 - \exp(-d / 50)\} \exp(-d / 6000) \quad \text{dB} \quad (46)$$

If necessary, the value of  $\delta E_1$  must be limited as follows:

- $\delta E_1$  must be limited such that the adjusted field strength does not exceed the adjusted maximum field strength.
- If  $\Delta N$  is greater than zero,  $\delta E_1$  must be limited such that the difference between the adjusted maximum and  $h_1 = 10$  m field strengths is not greater than it is in the unadjusted curves. Note that this condition must not be applied when  $\Delta N$  is less than zero.

Adjust field strengths for other values of  $h_1$  such that they occupy the same proportional position between the maximum and  $h_1 = 10$  m field strength as the corresponding field strength in the unadjusted curves, using:

$$E'_n = E'_1 + (E_n - E_1)(E'_{max} - E'_1)/(E_{max} - E_1) \quad (47)$$

where:

$E_1$ : field strength for  $h_1 = 10$  m

$E_n$ : field strength for  $h_1$  values greater than 10 m

$E_{max}$ : maximum field strength

and primes indicate adjusted values.

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