

International Telecommunication Union

ITU-R
Radiocommunication Sector of ITU

Recommendation ITU-R P.1546-6
(08/2019)

**Method for point-to-area predictions
for terrestrial services in the frequency
range 30 MHz to 4 000 MHz**

P Series
Radiowave propagation



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

Electronic Publication
Geneva, 2019

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RECOMMENDATION ITU-R P.1546-6

Method for point-to-area predictions for terrestrial services in the frequency range 30 MHz to 4 000 MHz

(2001-2003-2005-2007-2009-2013-2019)

Scope

This Recommendation describes a method for point-to-area radio propagation predictions for terrestrial services in the frequency range 30 MHz to 4 000 MHz. It is intended for use on tropospheric radio circuits over land paths, sea paths and/or mixed land-sea paths up to 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.

Keywords

Long range path-general propagation, tropospheric paths/circuits, field strength curves, time and location variability, basic transmission loss predictions

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 basic transmission loss for the aeronautical mobile service for the frequency range 125 MHz to 15.5 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 0.1 GHz;
- c) that Recommendation ITU-R P.617 provides guidance on the prediction of point-to-point (P-P) transmission 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 point-to-point propagation loss for terrestrial line-of-sight systems;
- f) that Recommendation ITU-R P.2001 provides a wide-range terrestrial propagation model for the frequency range 30 MHz to 50 GHz including both fading and enhancement statistics,

recommends

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 4 000 MHz and for distances up to 1 000 km.

NOTE – Long range propagation paths may also occur at VHF via the ionosphere. These modes are summarized in Recommendation ITU-R P.844.

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. 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 either the representative height of ground cover around the receiving/mobile antenna location, or 10 m, whichever is the higher. 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 Effect of clutter shielding transmitting/base antenna

If the transmitting/base antenna is over or adjacent to land on which there is clutter, the correction given in Annex 5, § 10 should be applied, irrespective of the transmitting/base antenna height above ground.

12 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.

13 Location variability

The propagation curves represent the field-strength values exceeded at 50% of locations within an area. 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.

14 Correction based on tropospheric scattering

Annex 5, § 13 gives a method for taking tropospheric scattering into account to be used if terrain information is available. In principle the curves should reflect the effect of any significant troposcatter signals, but it is not certain that sufficient measurements were conducted at the long distances required to capture such effects. The correction in Annex 5, § 13 is intended to make it unlikely that a field strength will be seriously under-predicted due to the curves not adequately representing tropo-scatter effects.

15 Correction for antenna height difference

Annex 5, § 14 gives a correction to account for the difference between the two antenna heights above ground.

16 Horizontal distances less than 1 km

The field strength curves cover horizontal distances from 1 km to 1 000 km. Annex 5, § 15 describes the method for horizontal distances less than 1 km.

17 Equivalent basic transmission loss

Annex 5, § 17 gives a method for converting from field strength for 1 kW e.r.p. to the equivalent basic transmission loss.

18 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 7 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.

19 Compatibility with the Okumura-Hata method

Annex 8 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.

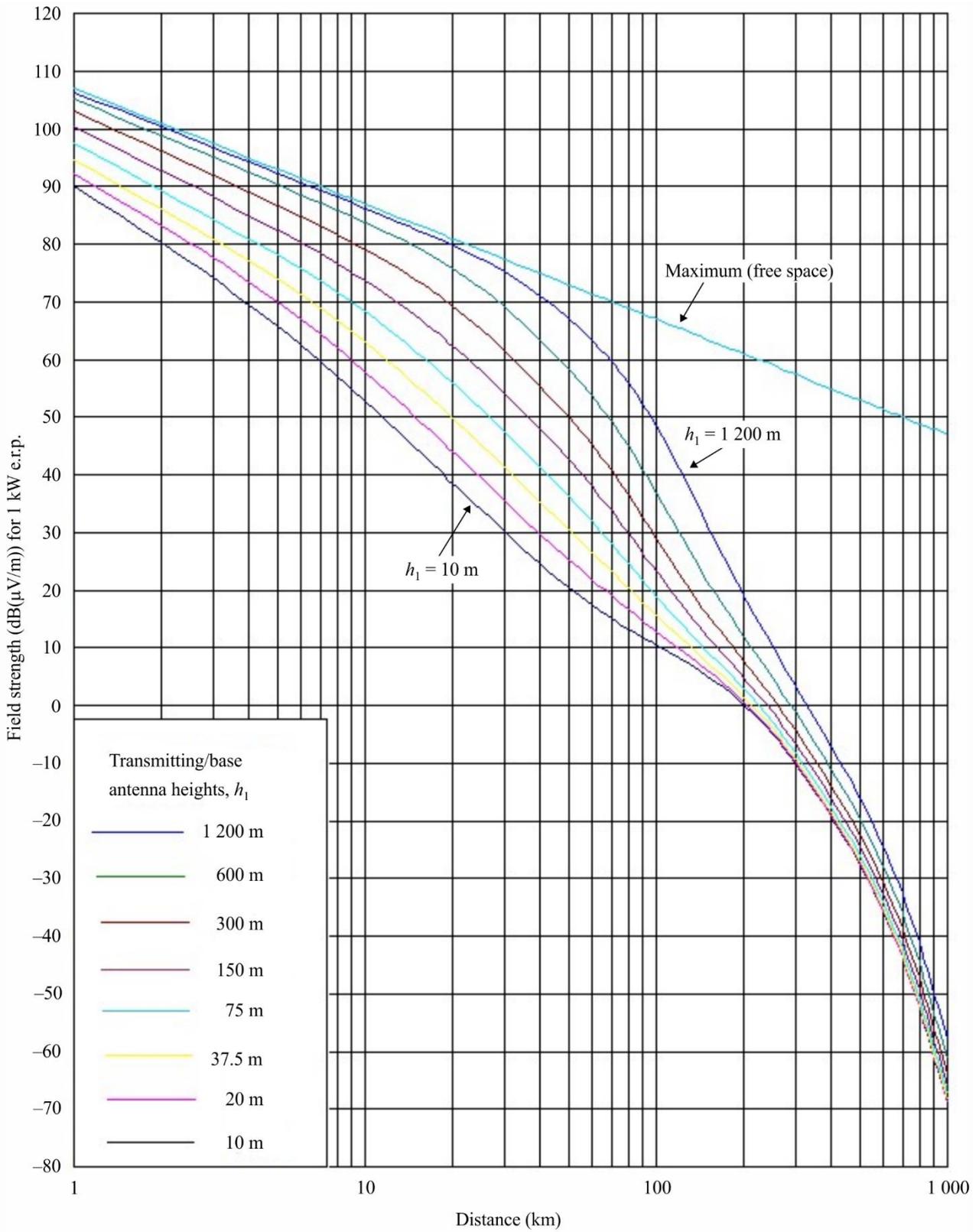
3 The field strength distribution as a function of percentage location may be calculated using the information in Annex 5, § 12.

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, § 18.

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.)

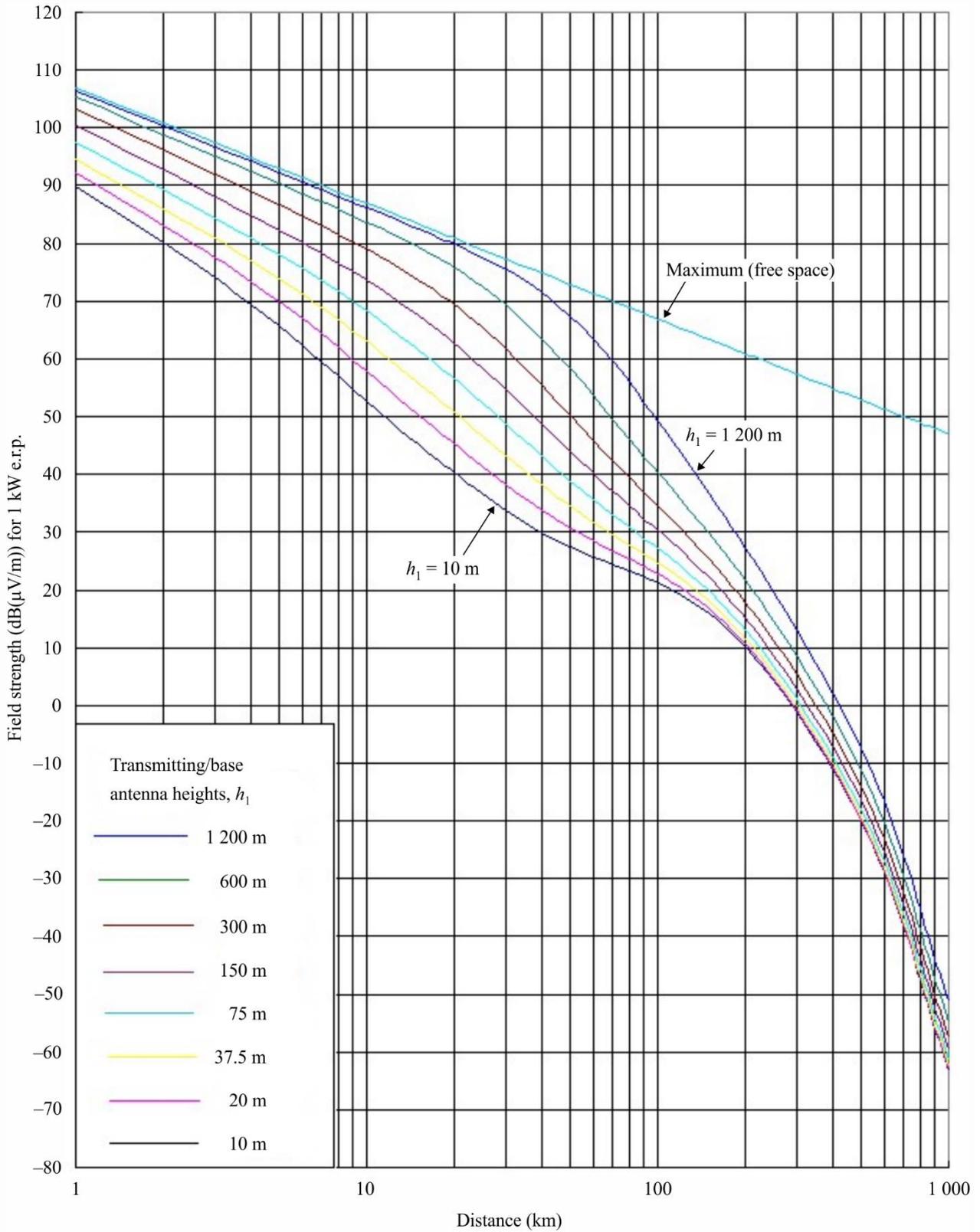
FIGURE 1
100 MHz, land path, 50% time



50% of locations

h_2 : representative clutter height

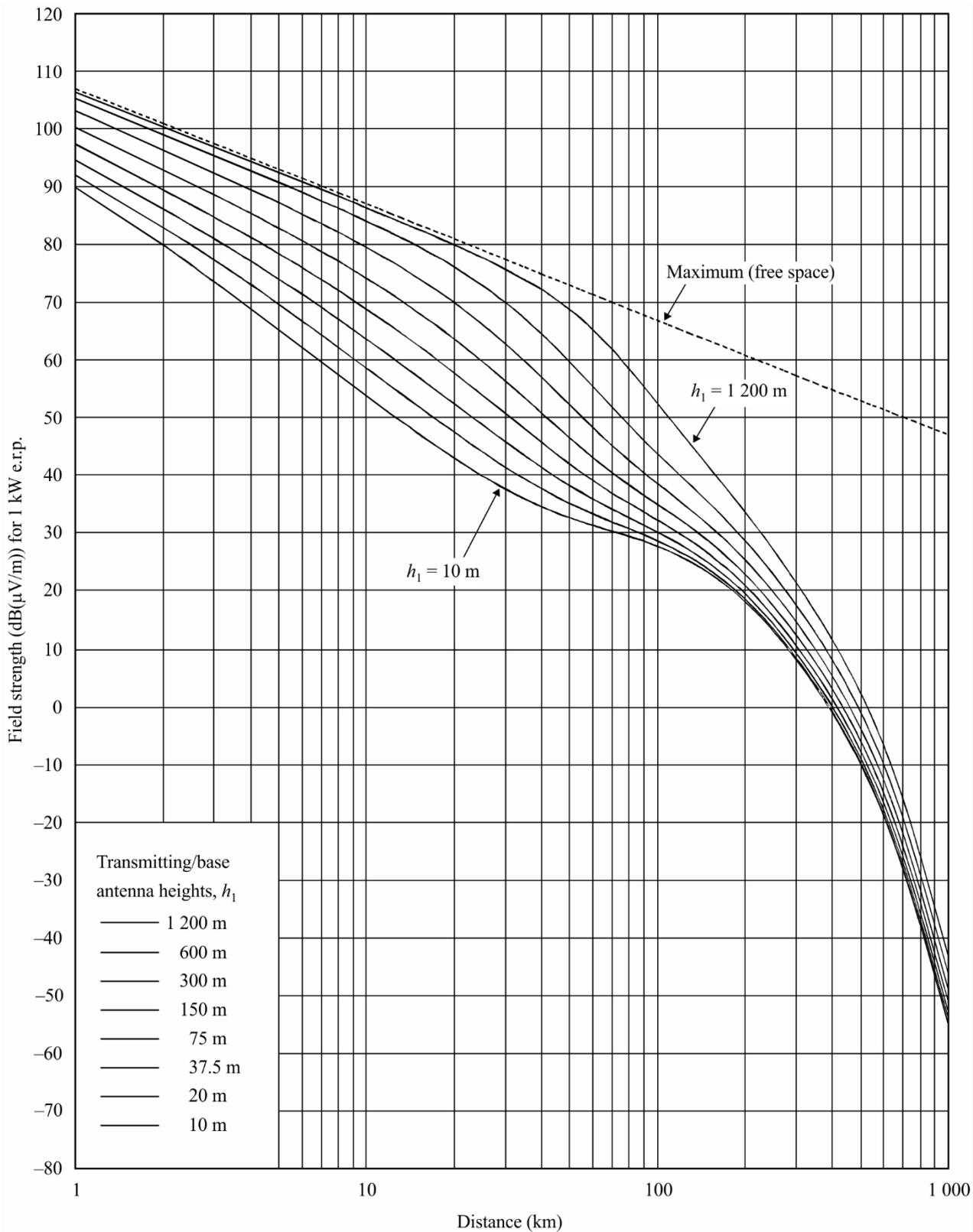
FIGURE 2
100 MHz, land path, 10% time



50% of locations

h_2 : representative clutter height

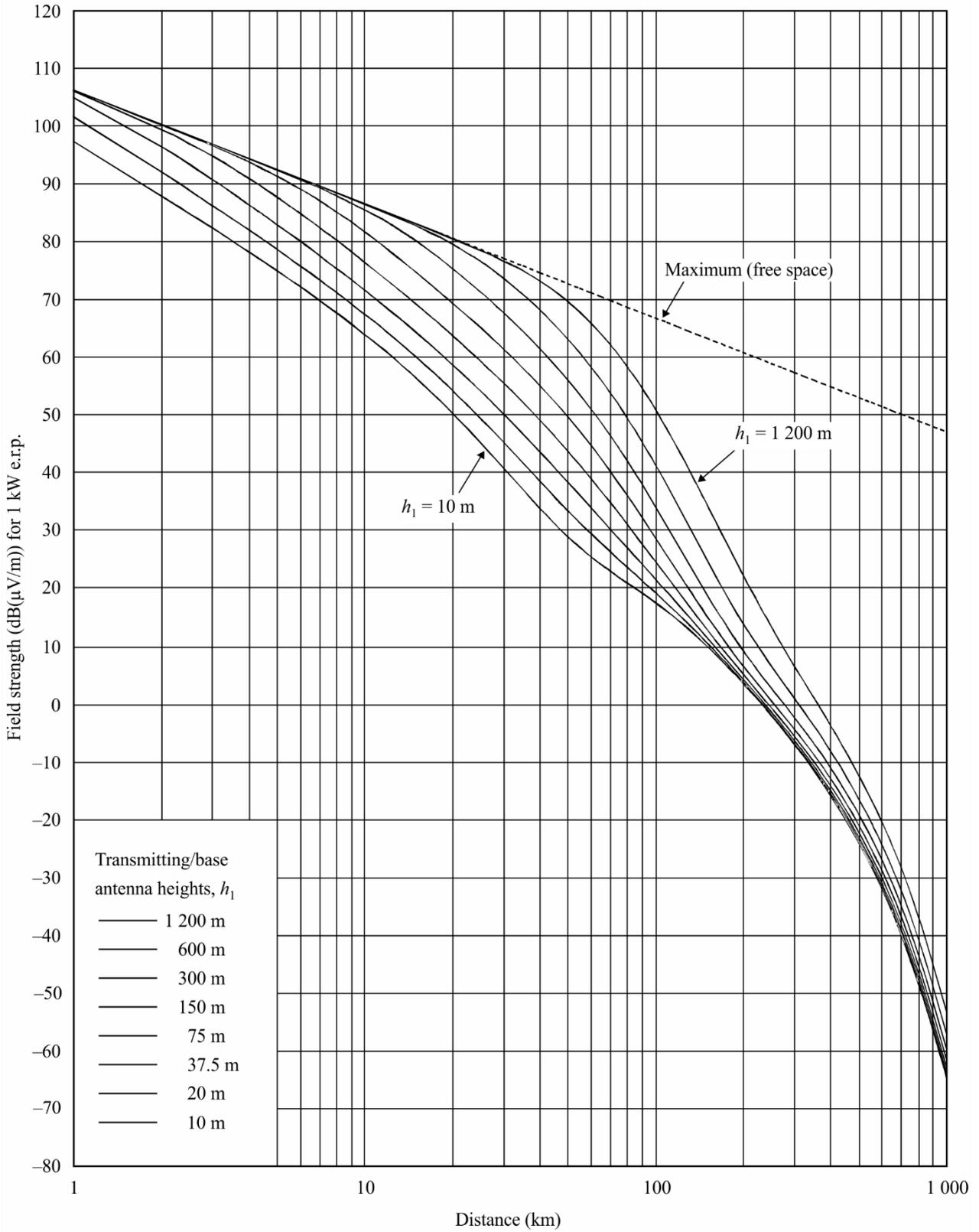
FIGURE 3
100 MHz, land path, 1% time



50% of locations

h_2 : representative clutter height

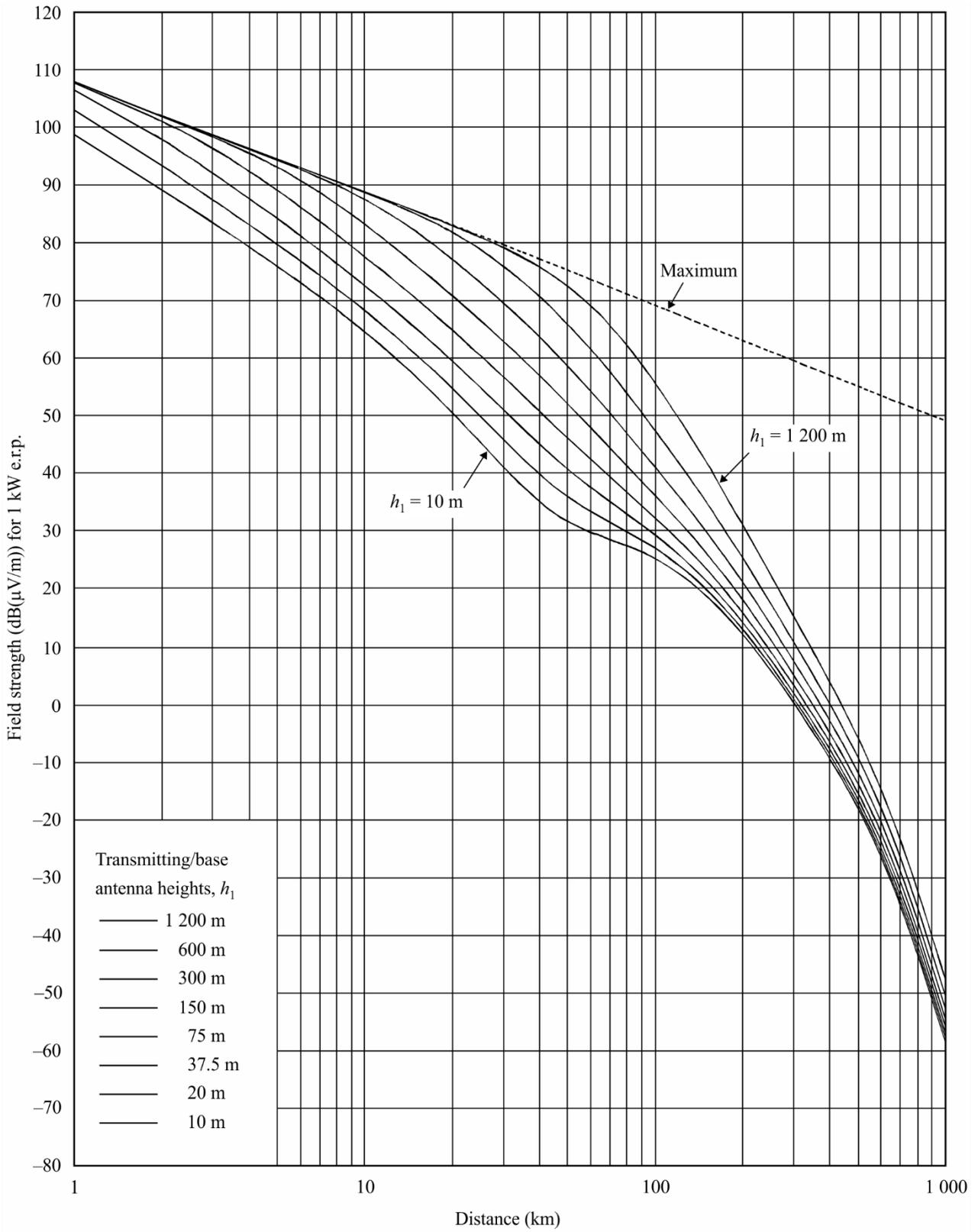
FIGURE 4
100 MHz, sea path, 50% time



50% of locations

$h_2 = 10$ m

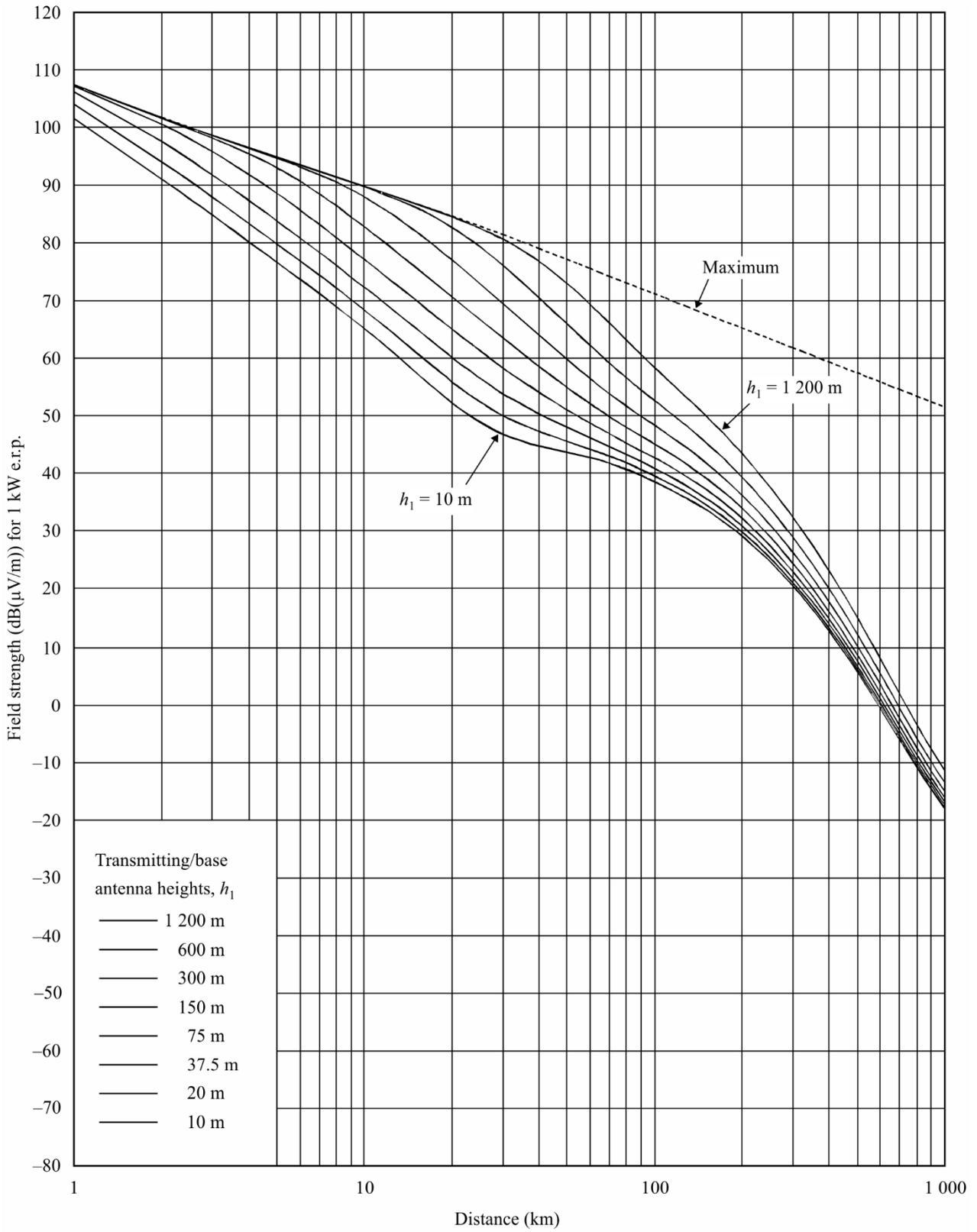
FIGURE 5
100 MHz, cold sea path, 10% time



50% of locations

$h_2 = 10\ \text{m}$

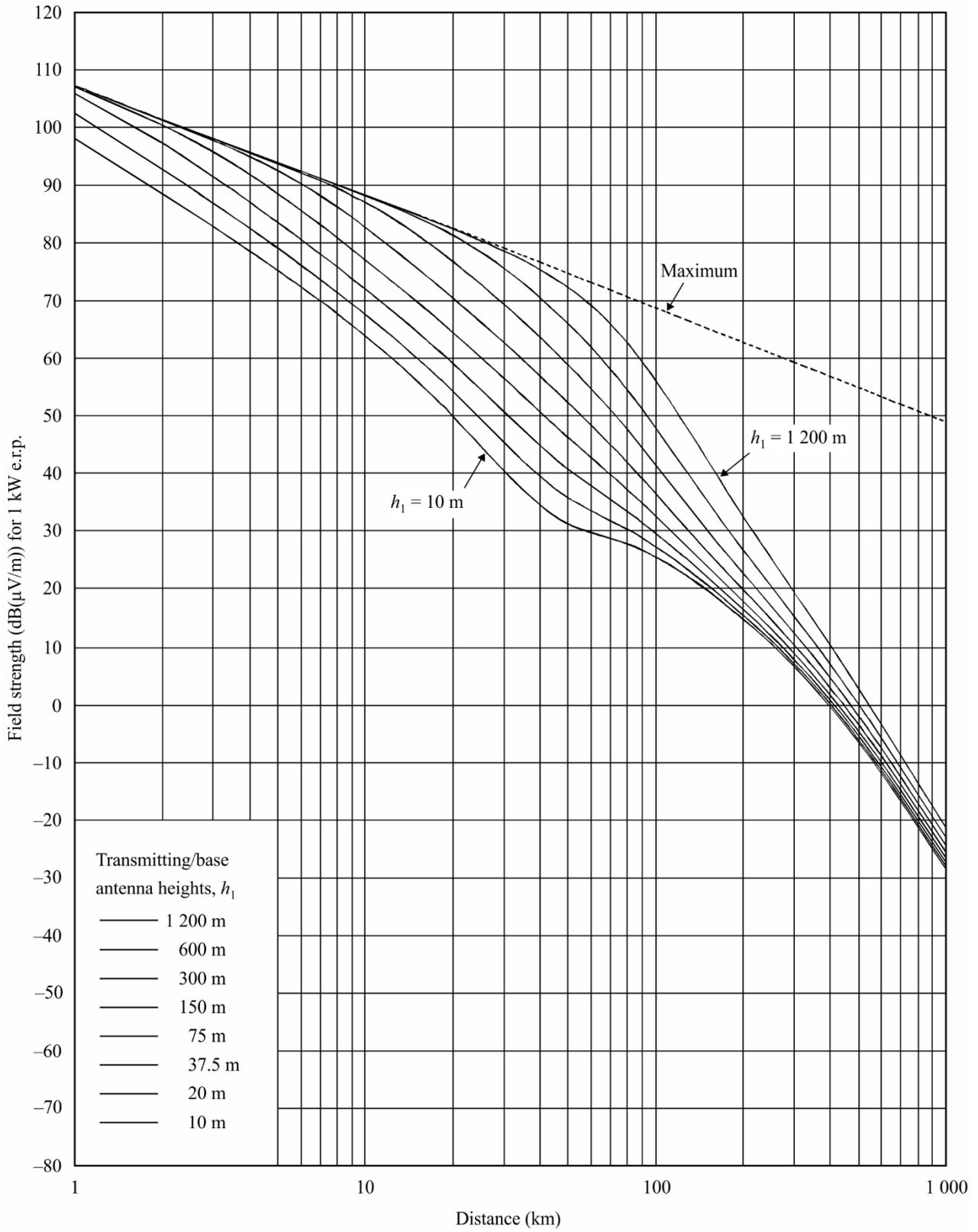
FIGURE 6
100 MHz, cold sea path, 1% time



50% of locations

$h_2 = 10$ m

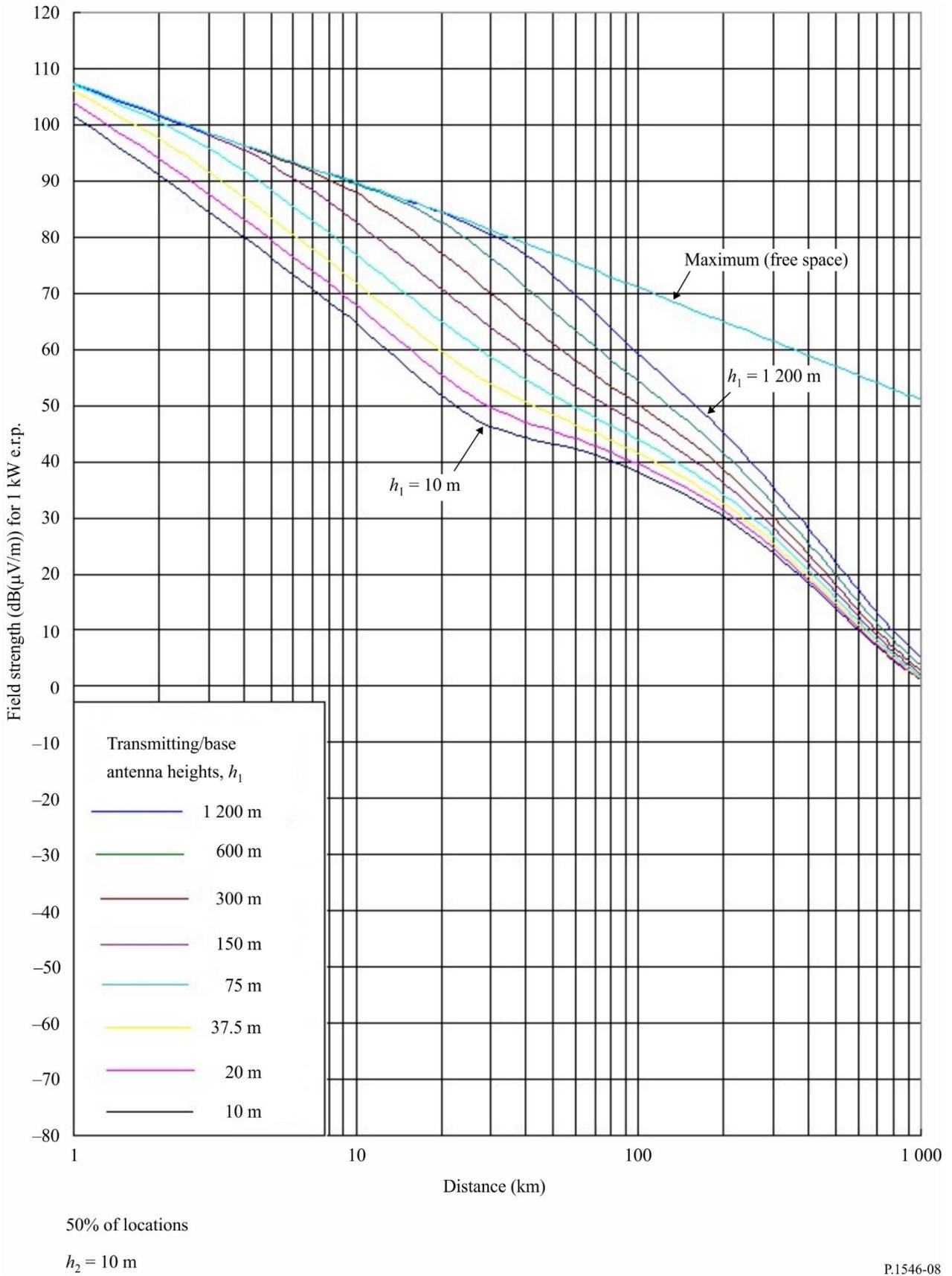
FIGURE 7
100 MHz, warm sea path, 10% time



50% of locations

$h_2 = 10$ m

FIGURE 8
100 MHz, warm sea path, 1% time

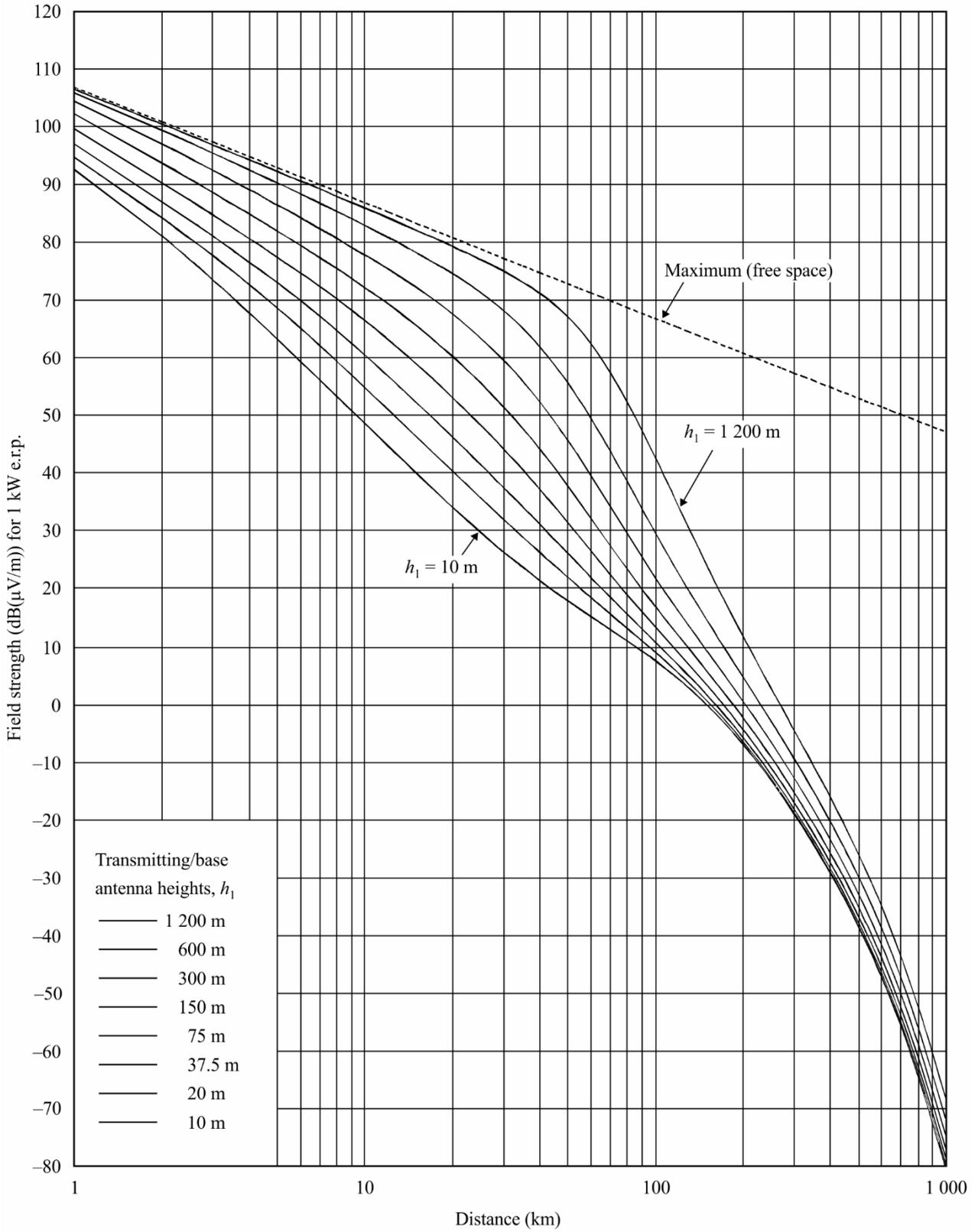


Annex 3

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, § 18.

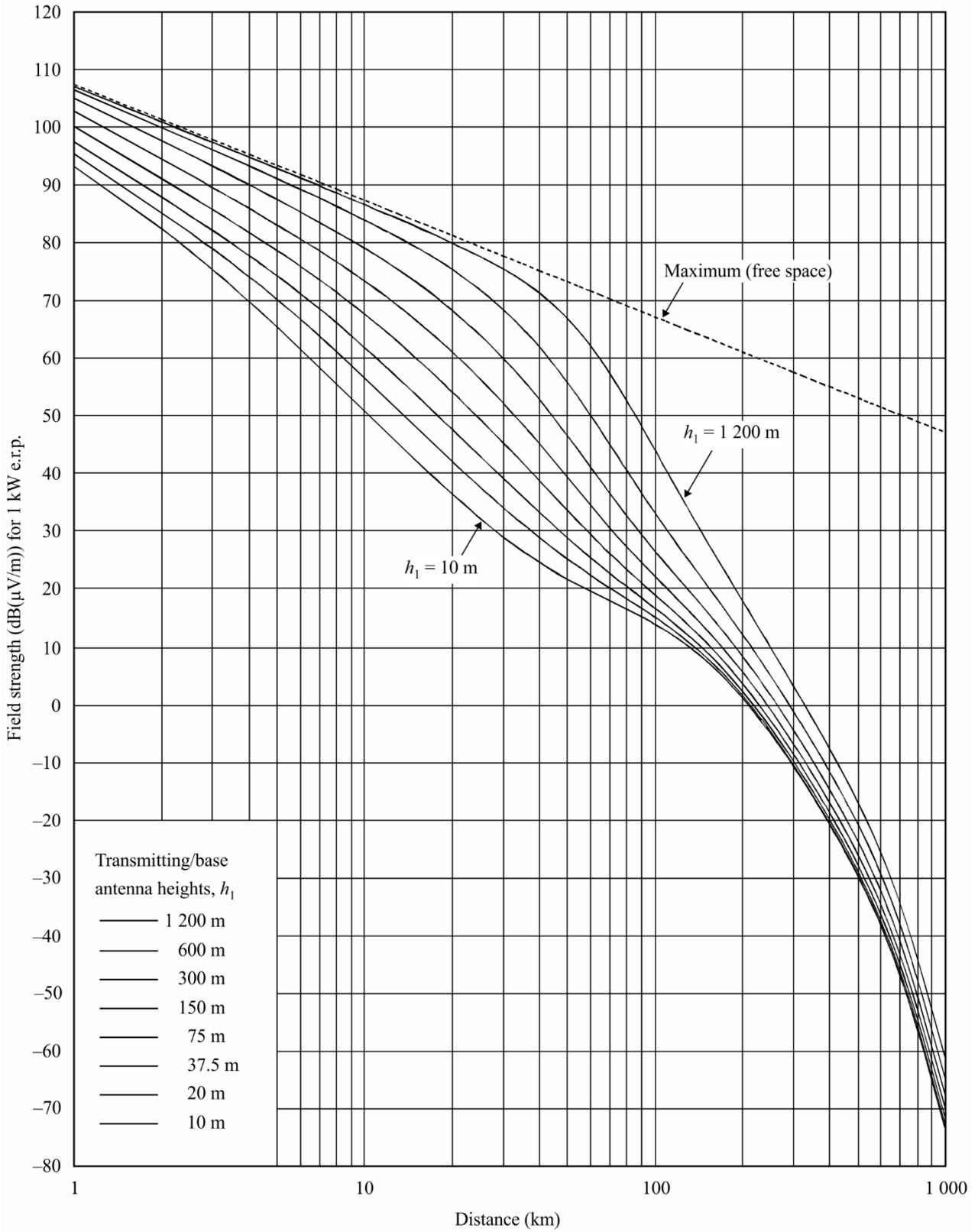
FIGURE 9
600 MHz, land path, 50% time



50% of locations

h_2 : representative clutter height

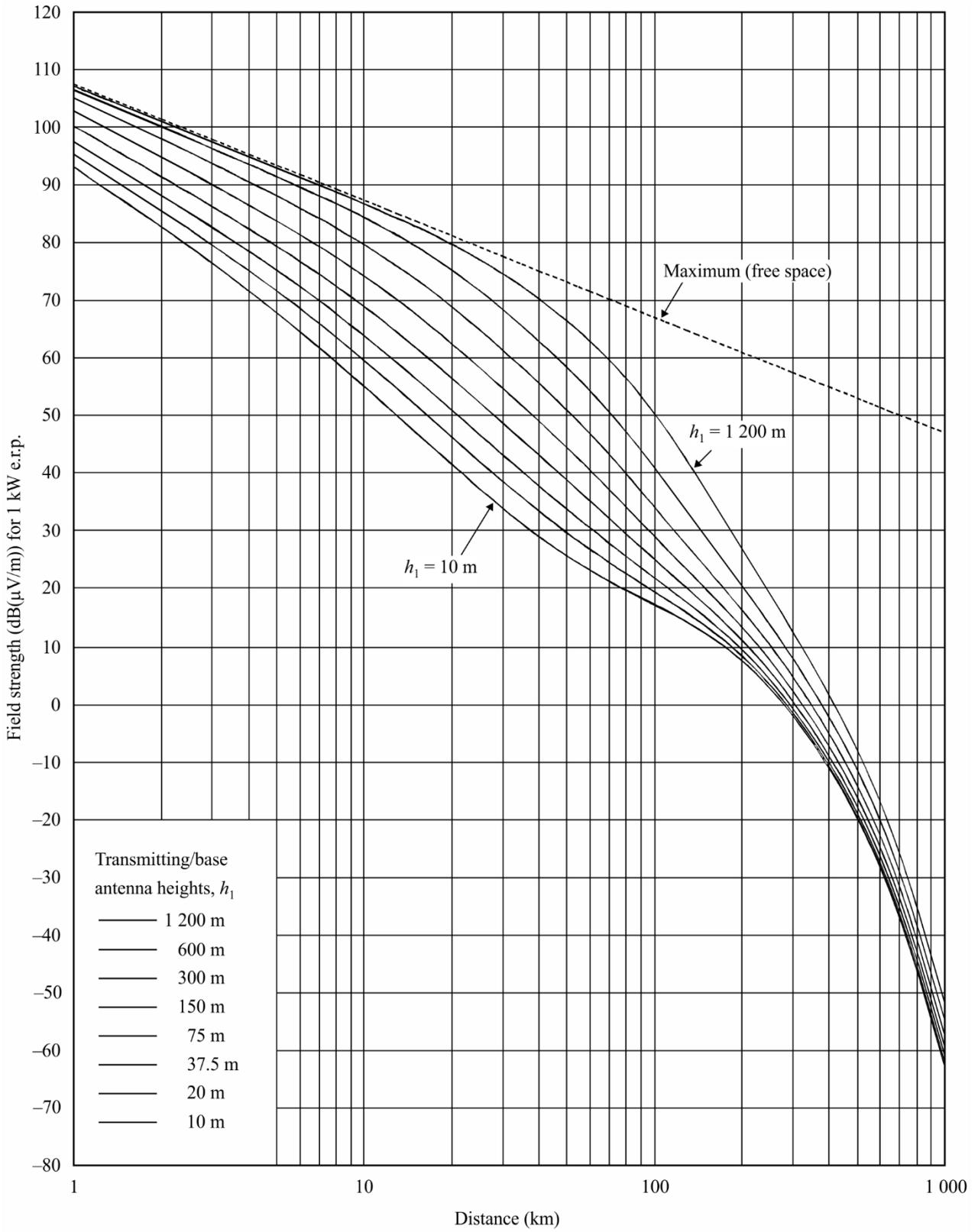
FIGURE 10
600 MHz, land path, 10% time



50% of locations

h_2 : representative clutter height

FIGURE 11
600 MHz, land path, 1% time

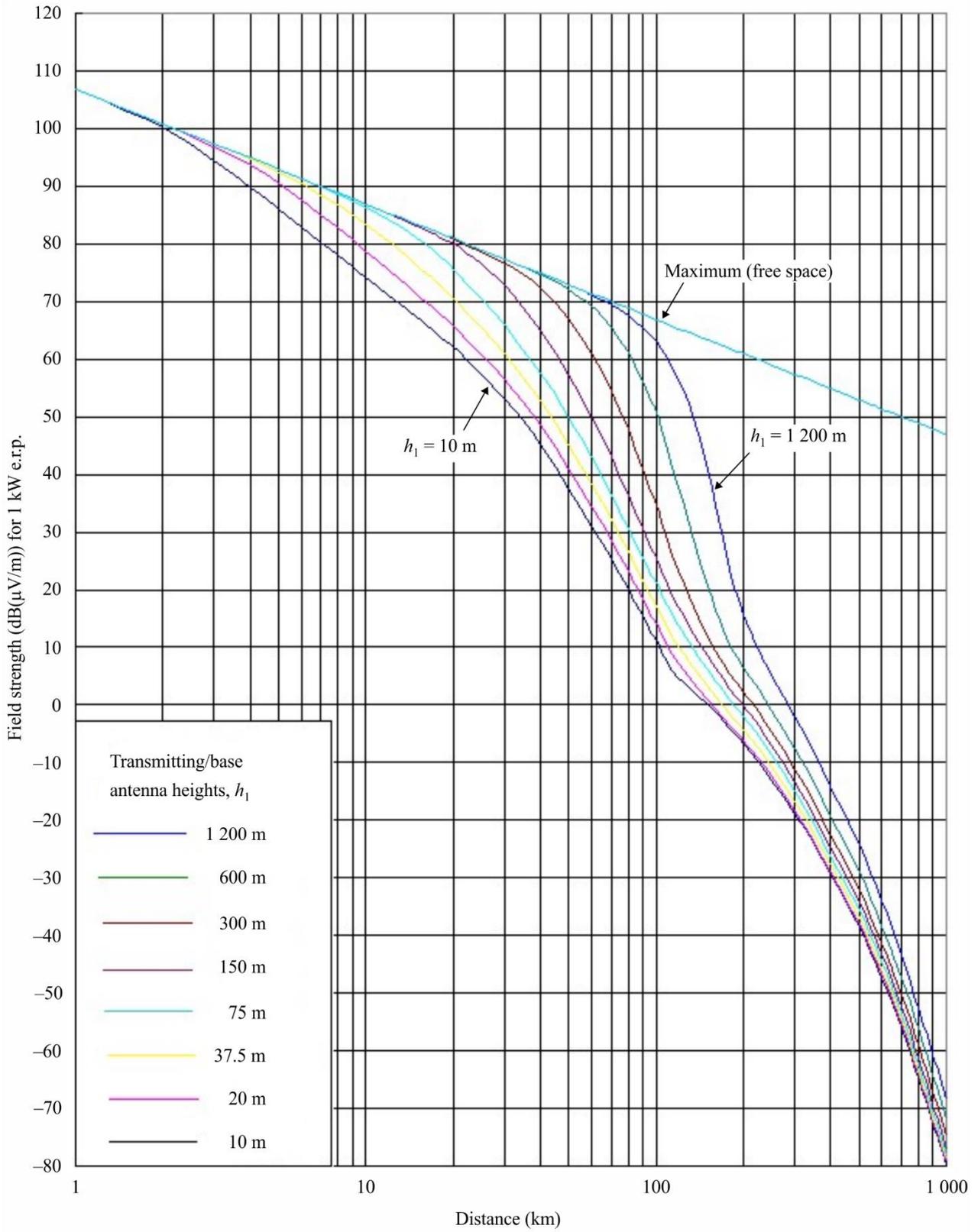


50% of locations

h_2 : representative clutter height

FIGURE 12

600 MHz, sea path, 50% time



50% of locations

$h_2 = 10$ m

FIGURE 13
600 MHz, cold sea path, 10% time

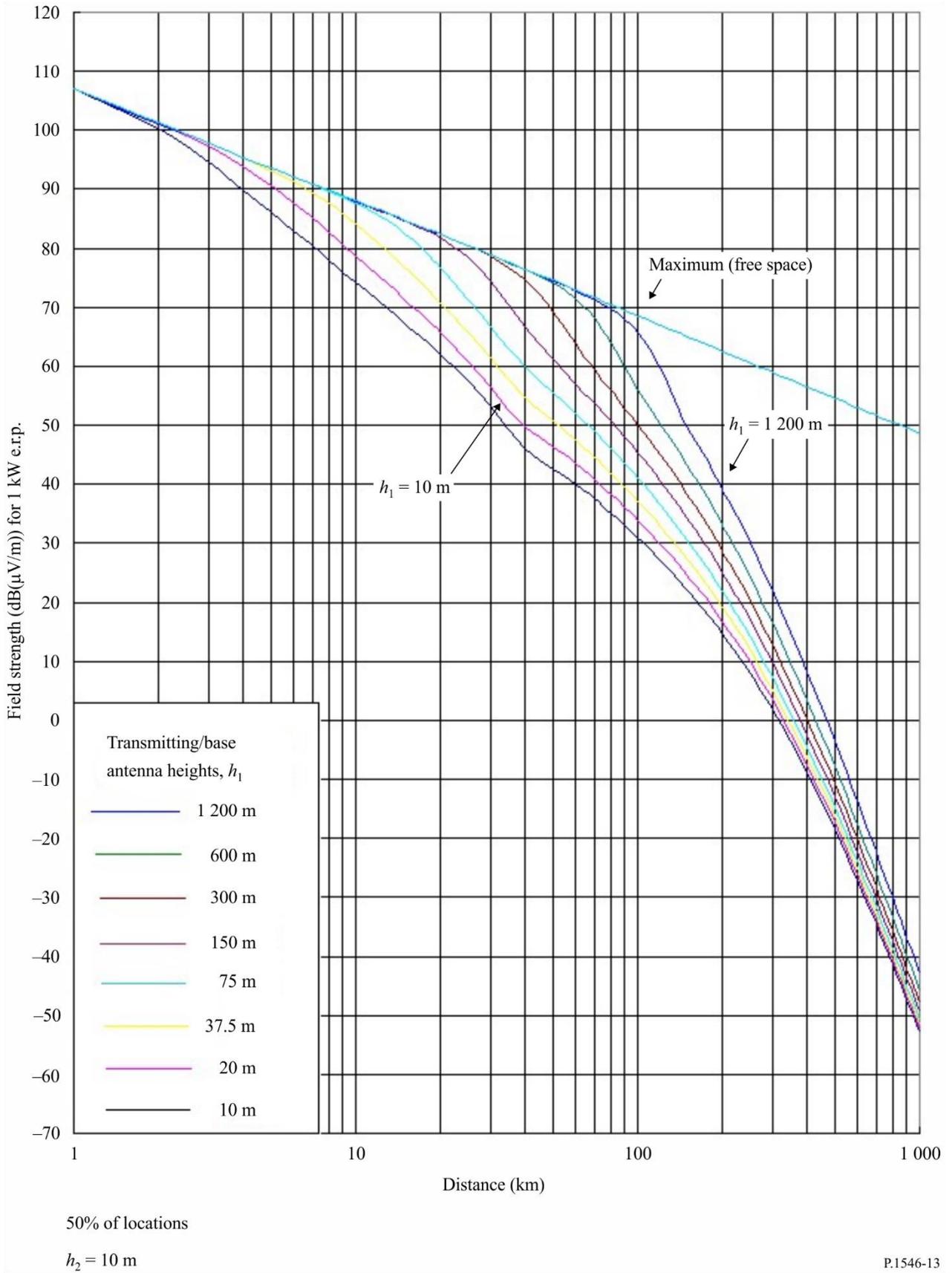
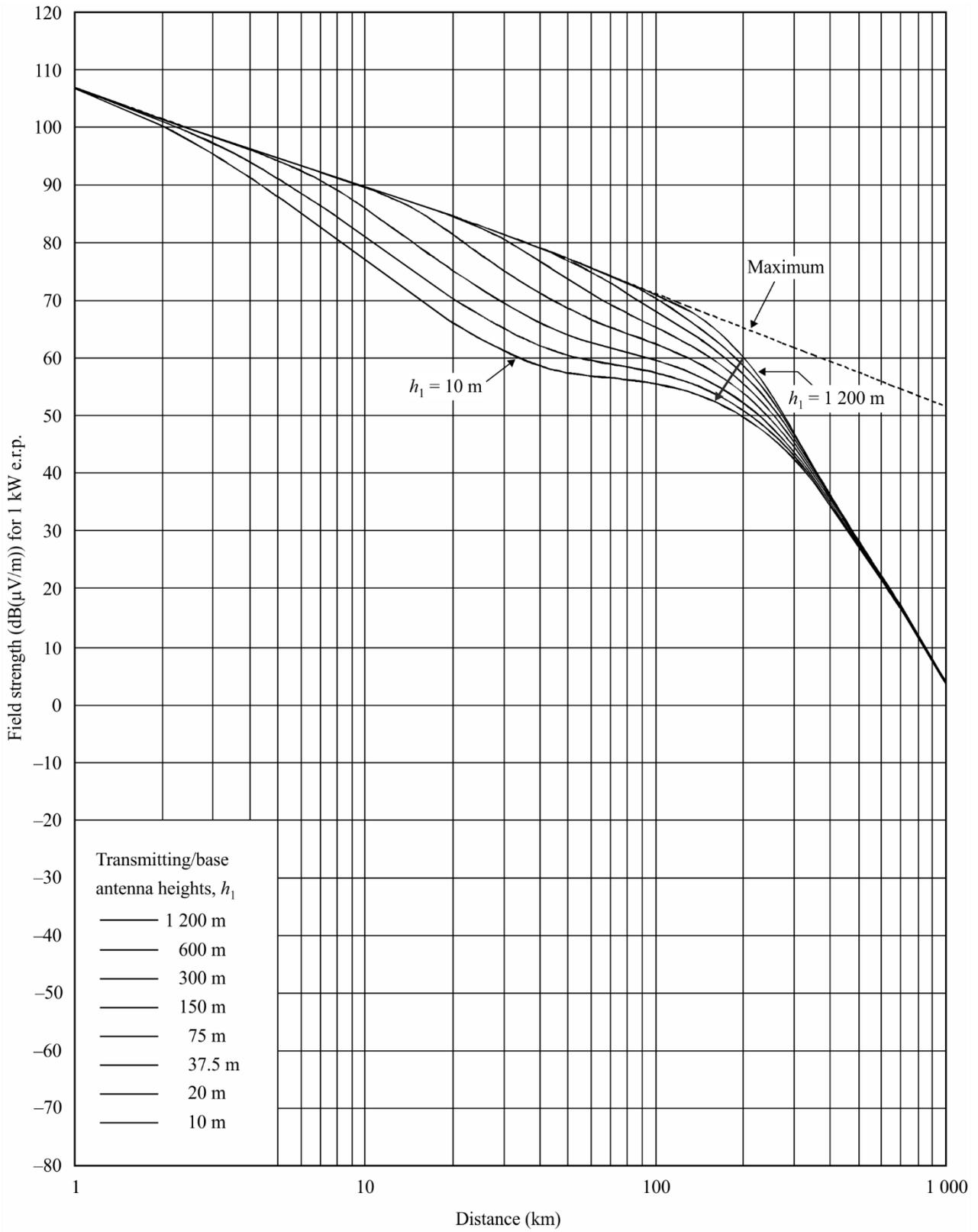


FIGURE 14
600 MHz, cold sea path, 1% time



50% of locations

$h_2 = 10\ m$

FIGURE 15
600 MHz, warm sea path, 10% time

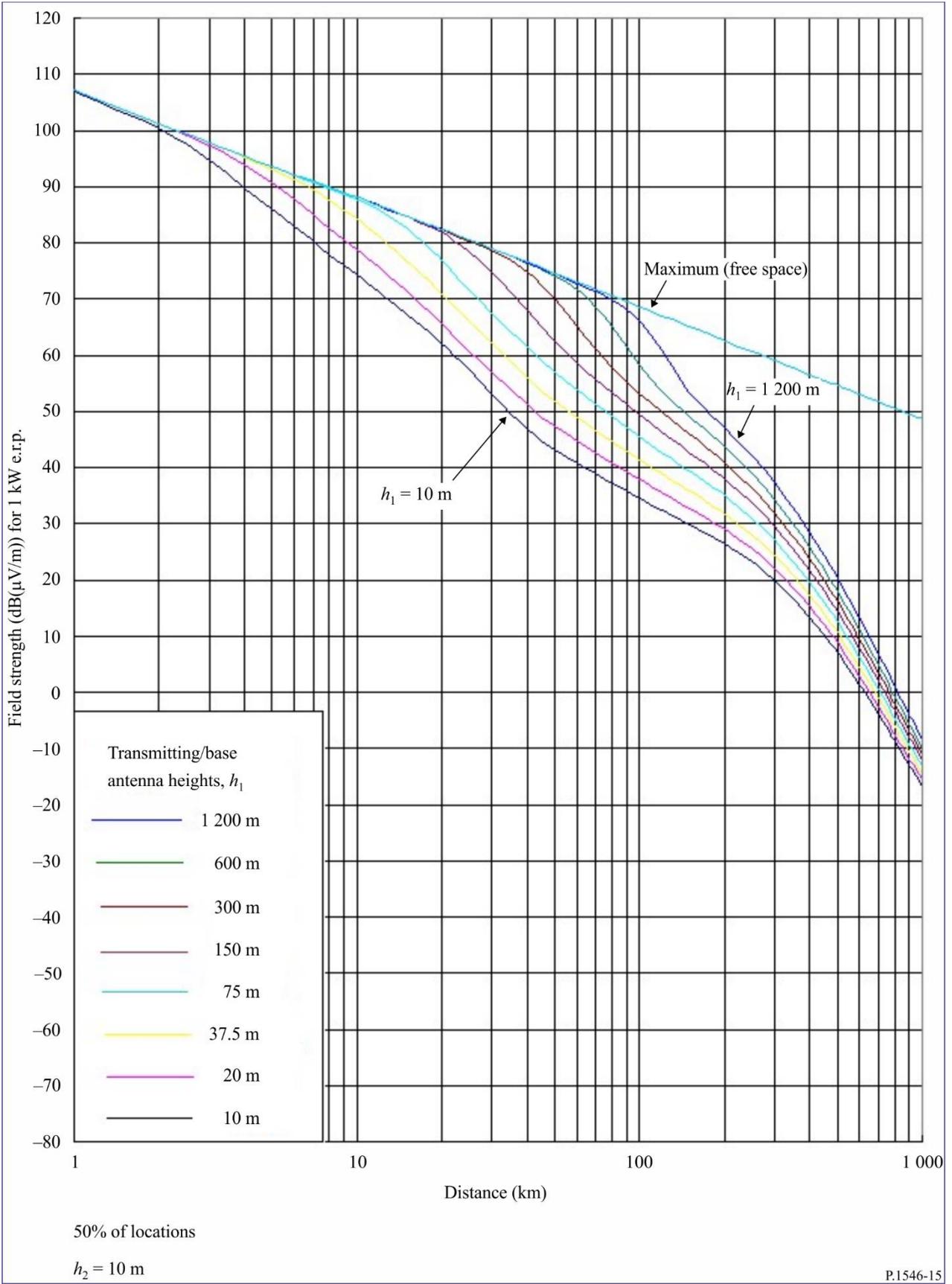
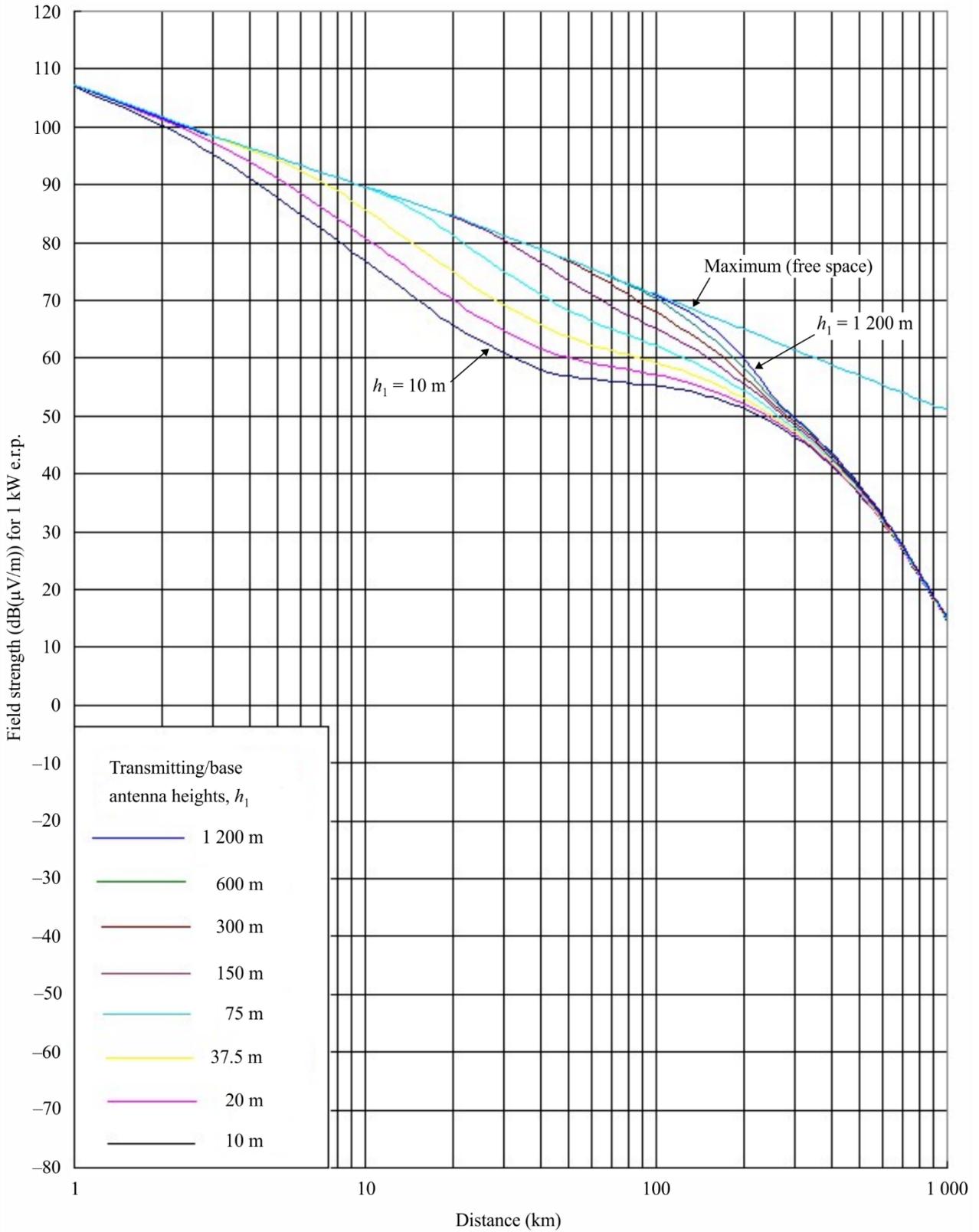


FIGURE 16
600 MHz, warm sea path, 1% time



50% of locations

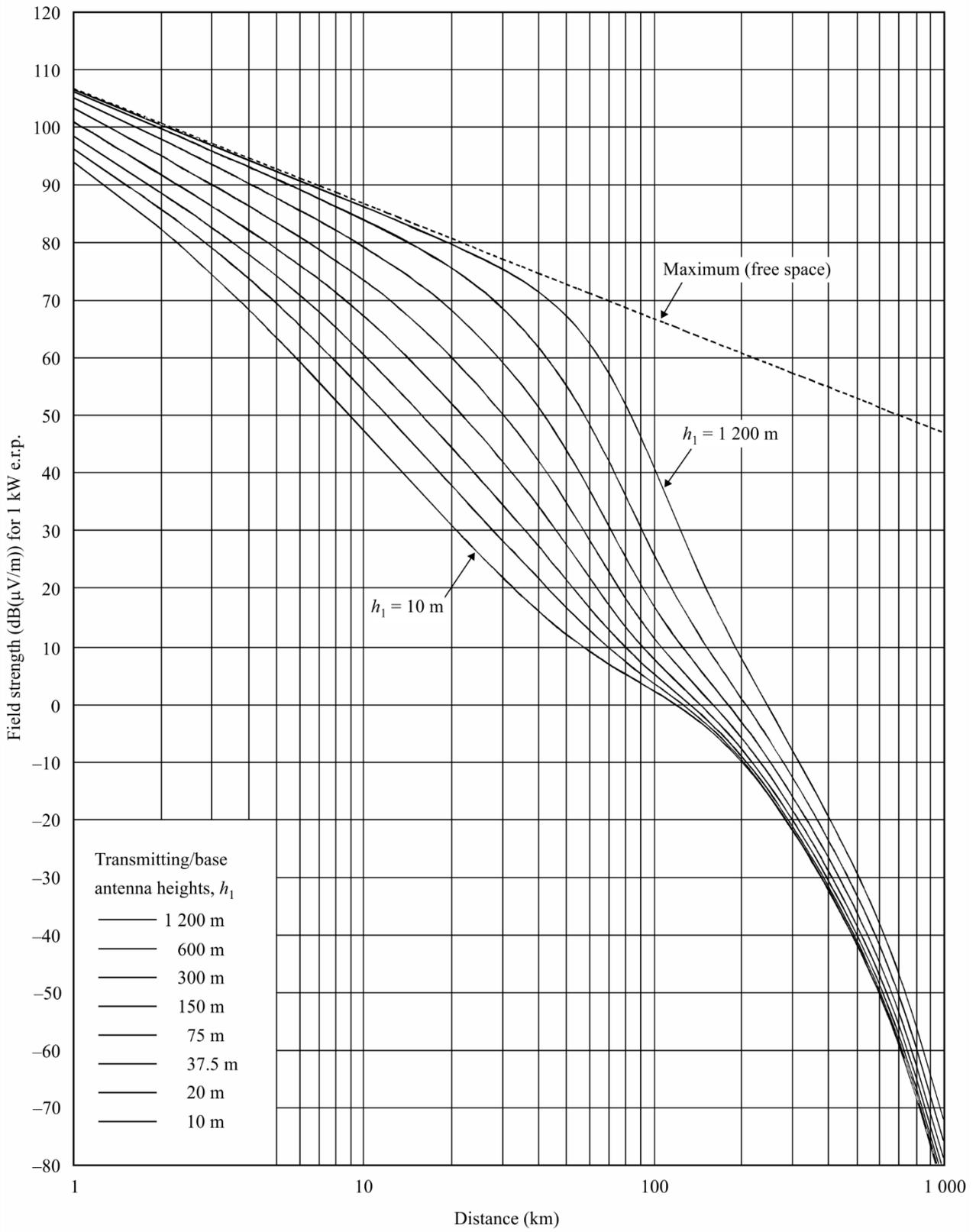
$h_2 = 10\ \text{m}$

Annex 4

Frequency range 1 000 MHz to 4 000 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 4 000 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, § 18.

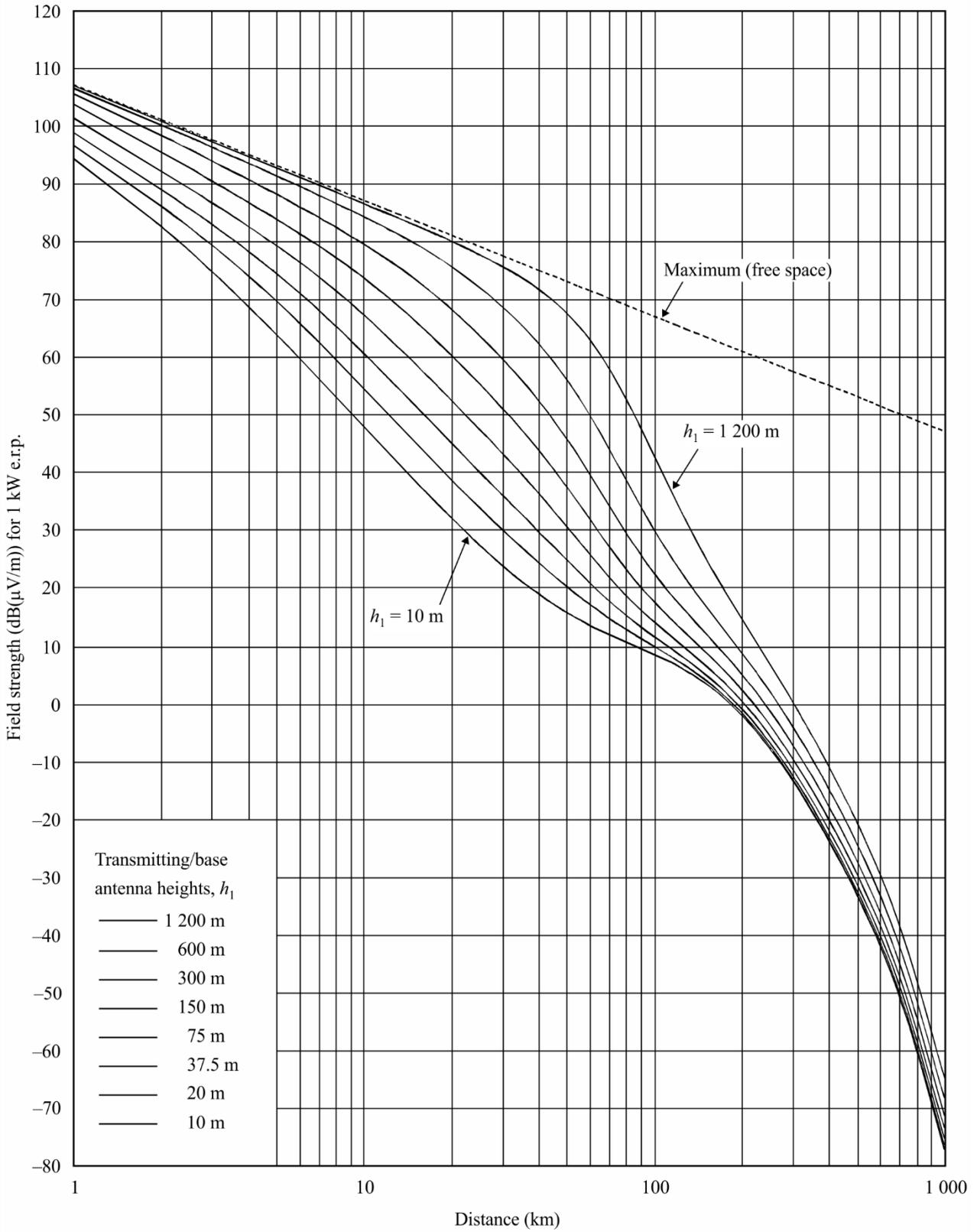
FIGURE 17
2 000 MHz, land path, 50% time



50% of locations

h_2 : representative clutter height

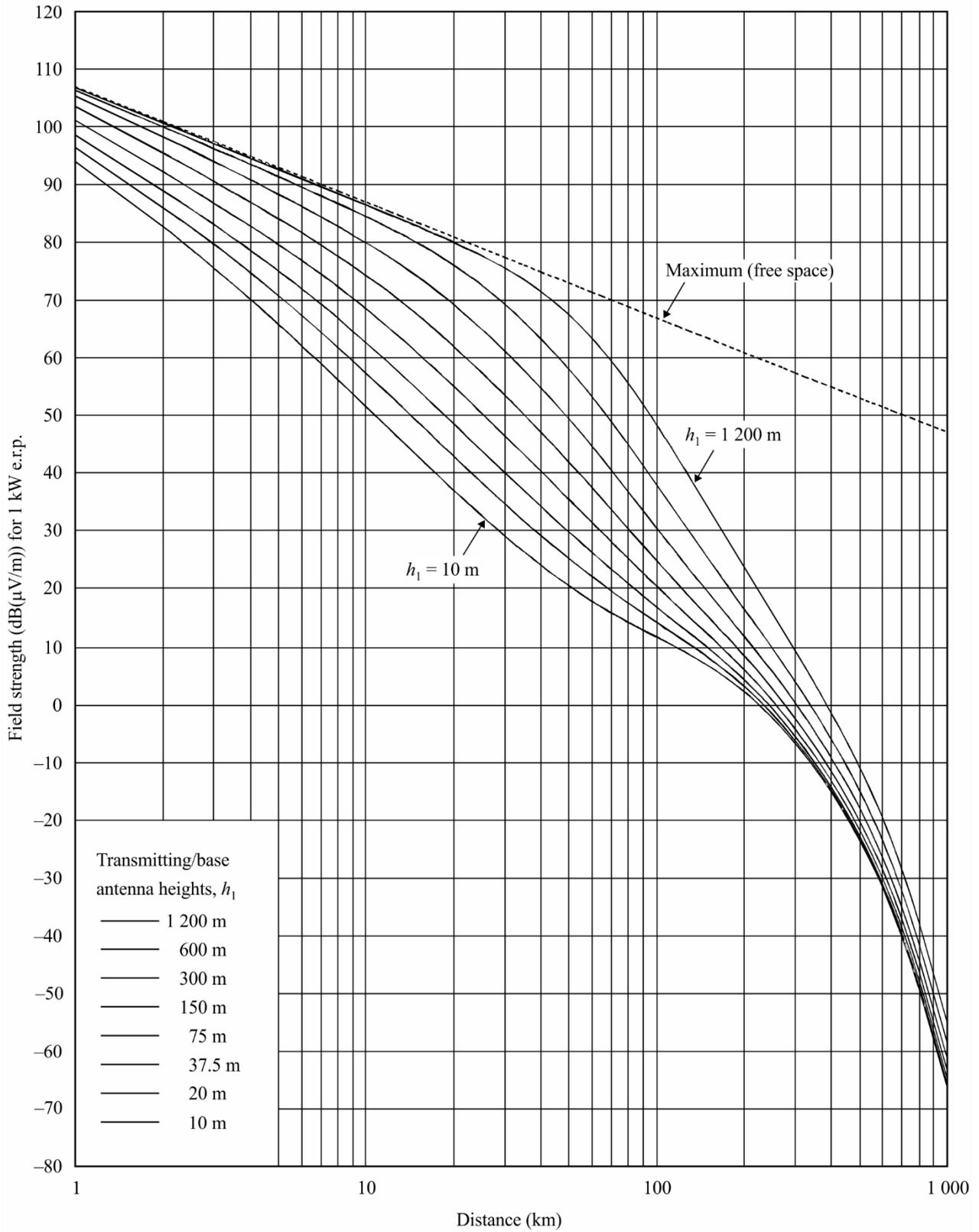
FIGURE 18
2 000 MHz, land path, 10% time



50% of locations

h_2 : representative clutter height

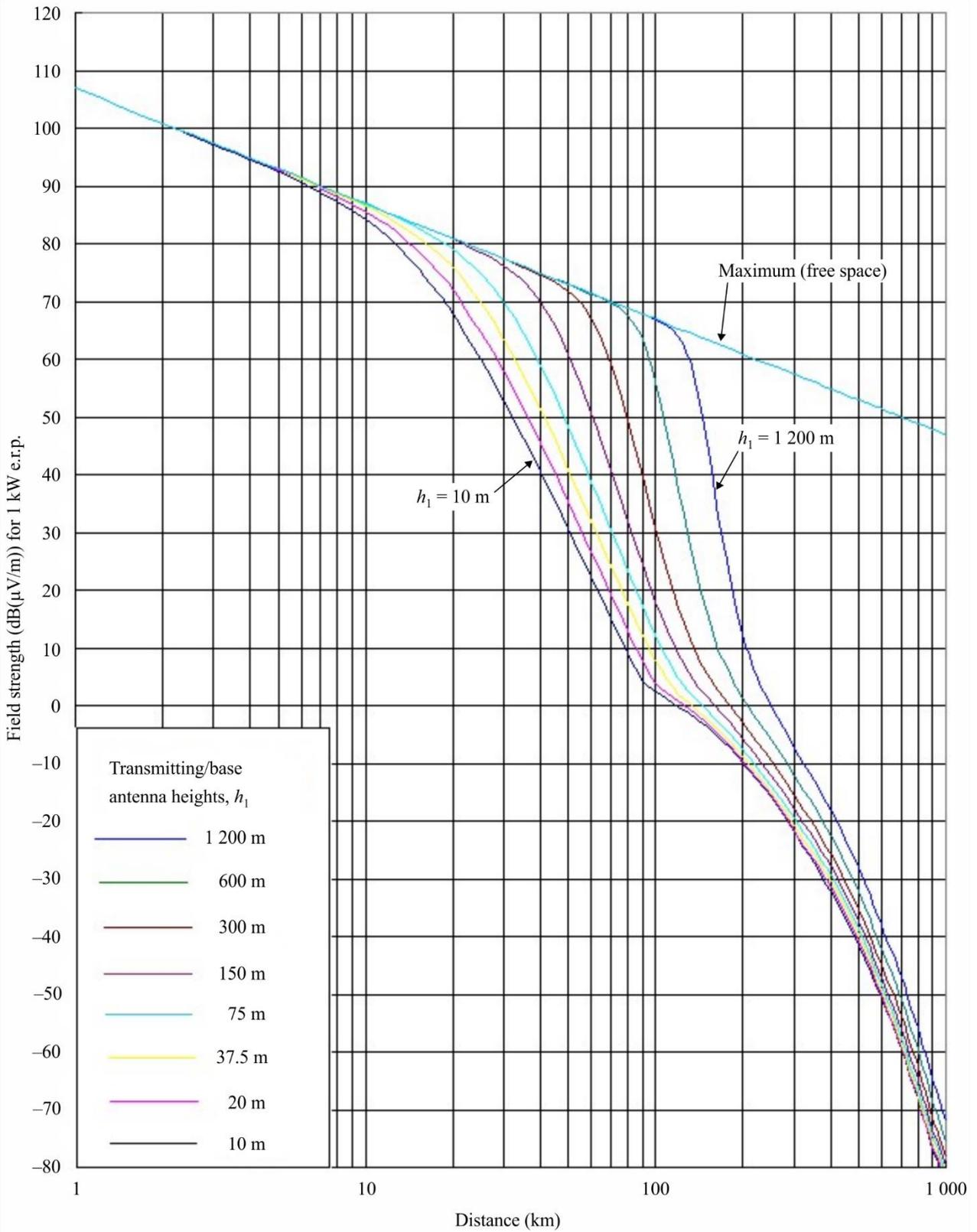
FIGURE 19
2 000 MHz, land path, 1% time



50% of locations

h_2 : representative clutter height

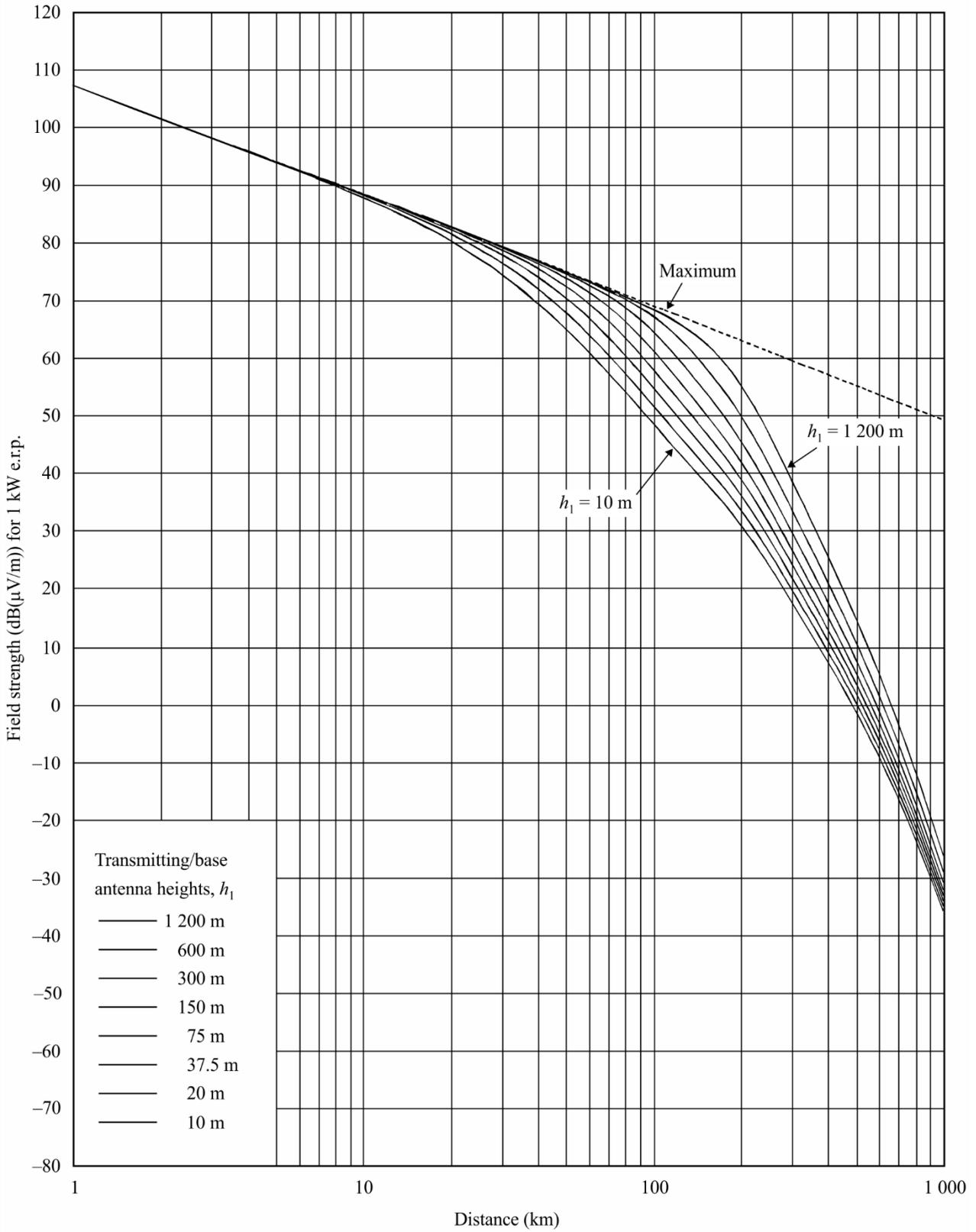
FIGURE 20
2 000 MHz, sea path, 50% time



50% of locations

$h_2 = 10$ m

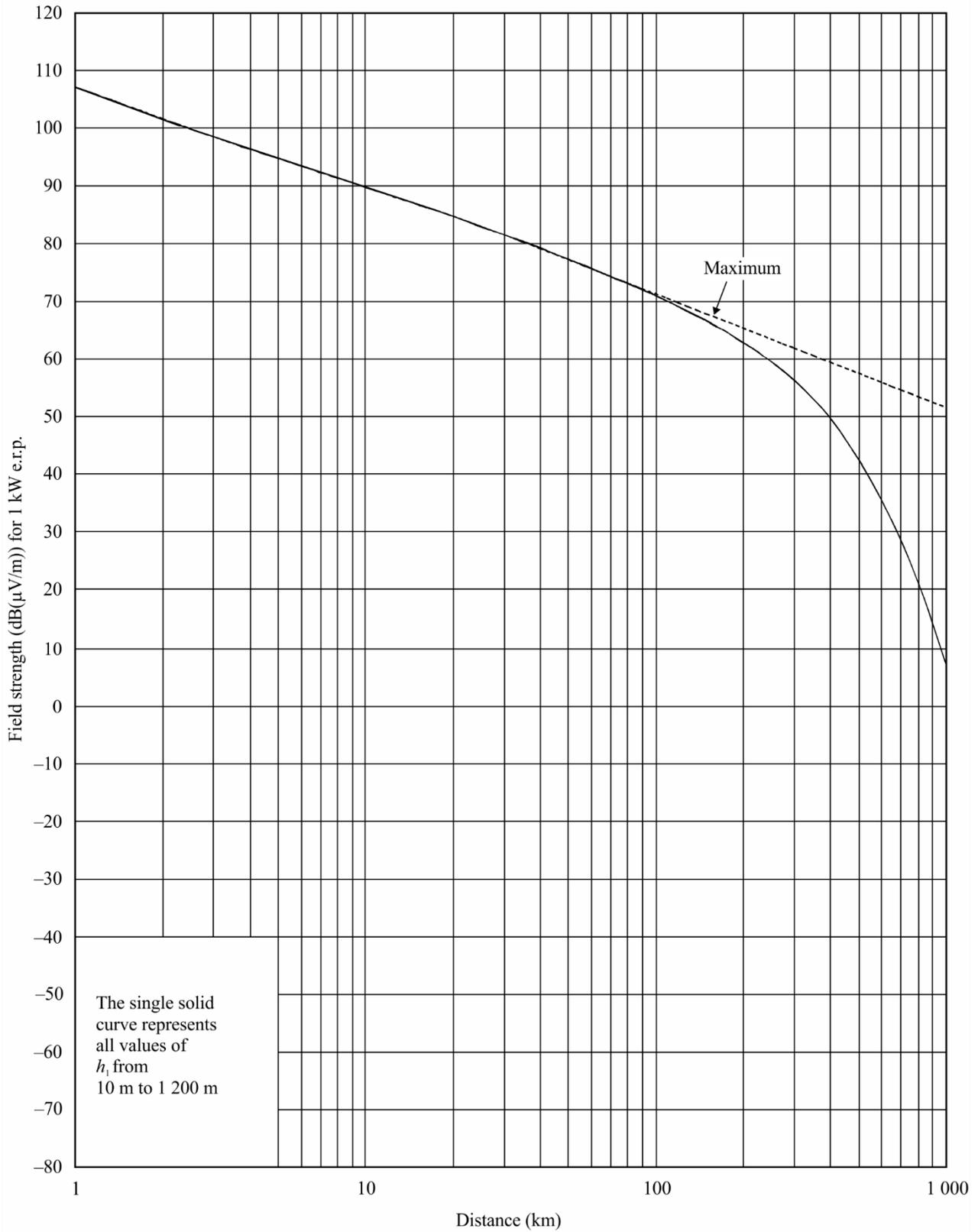
FIGURE 21
2 000 MHz, cold sea path, 10% time



50% of locations

$h_2 = 10$ m

FIGURE 22
2 000 MHz, cold sea path, 1% time

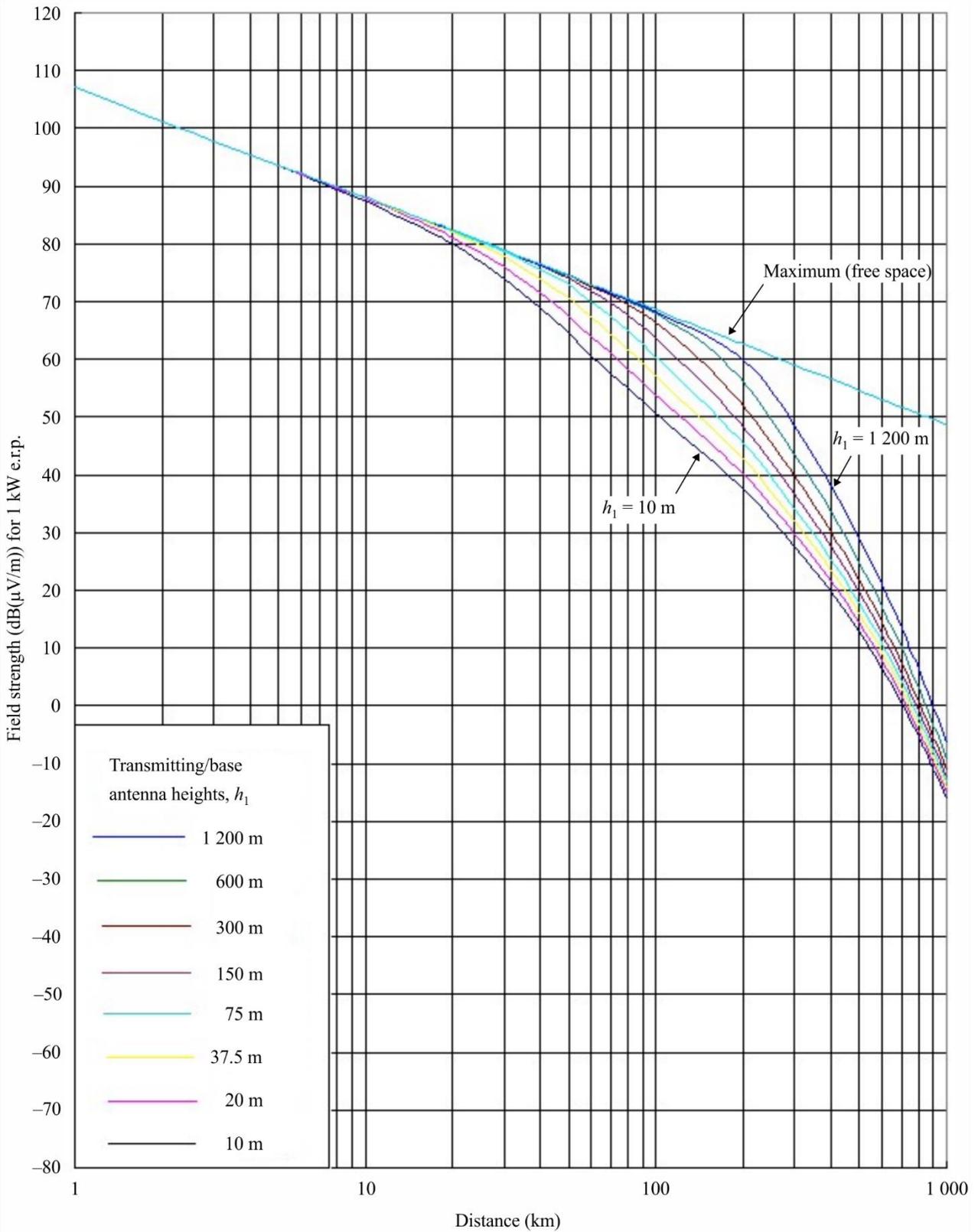


The single solid curve represents all values of h_1 from 10 m to 1 200 m

50% of locations

$h_2 = 10$ m

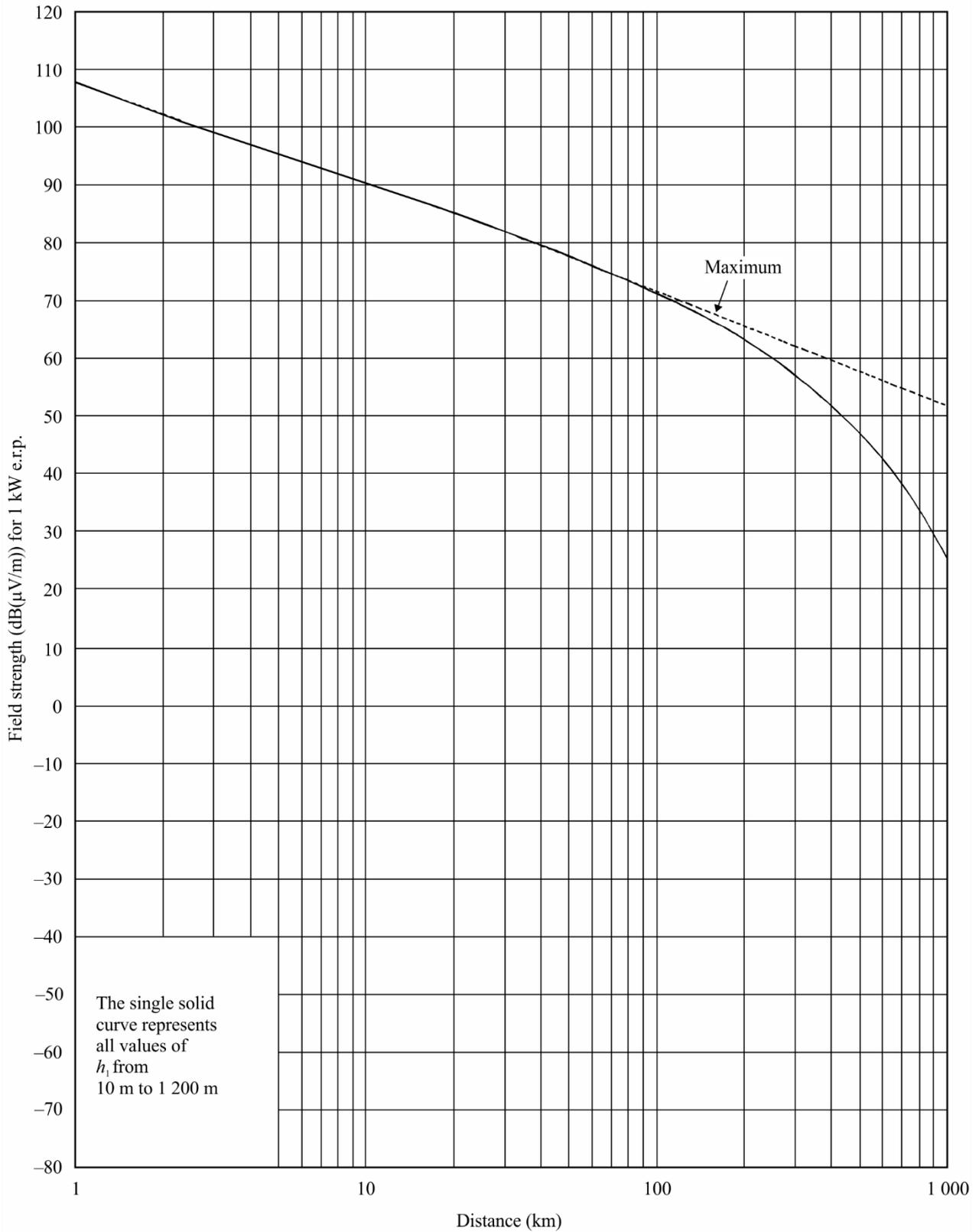
FIGURE 23
2 000 MHz, warm sea path, 10% time



50% of locations

$h_2 = 10$ m

FIGURE 24
2 000 MHz, warm sea path, 1% time



50% of locations

$h_2 = 10$ m

Annex 5

Additional information and methods for implementing the prediction method

1 Introduction

This Annex describes separate stages of the calculation, although not necessarily in the order of calculation. A step-by-step description of the overall method given in Annex 6 should be followed.

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 14 describe corrections to be added to the field strength predictions for additional precision. Section 15 describes the method for paths shorter than 1 km. Sections 16 to 18 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. 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 at or below the levels of clutter in their respective vicinities, then the terminal with the greater height above ground should be treated as the transmitting/base station;
- b) if one terminal is in an open location or above the surrounding clutter, whereas the other terminal is at or below the level of clutter, then the open/uncluttered terminal should be treated as the transmitting/base station;
- c) if both terminals are open/uncluttered, then the terminal with the greater effective height should be treated as the transmitting/base station.

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.

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. Note, it is possible that, using this method to determine h_1 , there will be non-monotonic modeling in the predicted field strength with distance, out to a distance of 15 km. While this may happen in reality, it may be an undesirable modeling of the model for certain applications. Therefore, if non-monotonic modeling must be avoided, then the value of h_1 should be fixed at a representative value for these cases.

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 3000 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:

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

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

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

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, θ_{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 θ_{ica} in equation (32c) 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, θ_{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:

$$J(v) = \left[6.9 + 20 \log \left(\sqrt{(v-0.1)^2 + 1} + v - 0.1 \right) \right] \quad \text{for } v > -0.7806 \quad (12a)$$

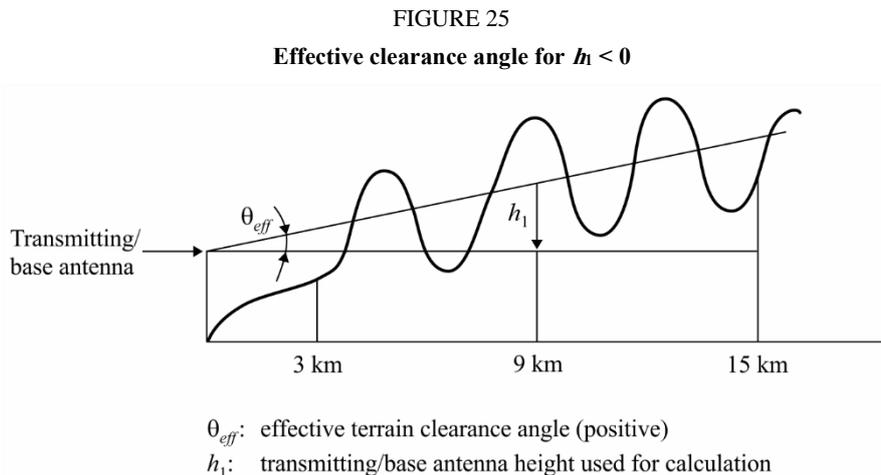
$$J(v) = 0 \quad \text{otherwise} \quad (12b)$$

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

and

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

$$\begin{aligned} K_v &= 1.35 && \text{for 100 MHz} \\ K_v &= 3.31 && \text{for 600 MHz} \\ K_v &= 6.00 && \text{for 2 000 MHz.} \end{aligned}$$



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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(μ 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 greater than 1 000 km.

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 2 000 MHz. In the case of frequencies below 100 MHz or above 2 000 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, 2 000 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 2 000 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:

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

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

where:

E_{max} : maximum field strength at the required distance as defined in § 2

E_{d_f} : 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.

An approximation to function $Q_i(x)$ is given in § 16 below.

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

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/base antenna at the representative clutter height at the receiving/mobile antenna, R_2 , 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 by:

$$A = A_0 (F_{sea})^V \quad (18)$$

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

$$A_0(F_{sea}) = 1 - (1 - F_{sea})^{2/3} \quad (19)$$

and V is calculated using the expression:

$$V = \max \left[1.0, 1.0 + \frac{\Delta}{40.0} \right] \quad (20)$$

with:

$$\Delta = E_{sea}(d_{total}) - E_{land}(d_{total}) \quad (21)$$

The following part up to equation (26) 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. 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 7, 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:

$$E = \sum_i \frac{d_i}{d_{total}} E_i(d_{total}) \quad (22)$$

where:

E : field strength for the mixed path (dB(μ V/m))

$E_i(d_{total})$: field strength for path in zone i equal in length to the mixed path (dB(μ V/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 (22) 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:

$$E = (1-A) \cdot \frac{\sum_{i=1}^{n_l} d_i E_{land,i}}{d_{lT}} + A \cdot \frac{\sum_{j=1}^{n_s} d_j E_{sea,j}}{d_{sT}} \quad (23)$$

where:

E : field strength for mixed path (dB(μ V/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(μ V/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(μ V/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 applicable to the method approved by RRC-06

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:

$$d_{sT} = \sum_{n=1}^{N_s} d_{sn} : \quad \text{total length of sea-and-coastal-land paths traversed} \quad (24a)$$

$$d_{lT} = \sum_{m=1}^{M_l} d_{lm} : \quad \text{total length of land paths traversed} \quad (24b)$$

$$d_{total} = d_{sT} + d_{lT} : \quad \text{length of the total propagation path} \quad (24c)$$

The following field-strength values are needed:

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

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

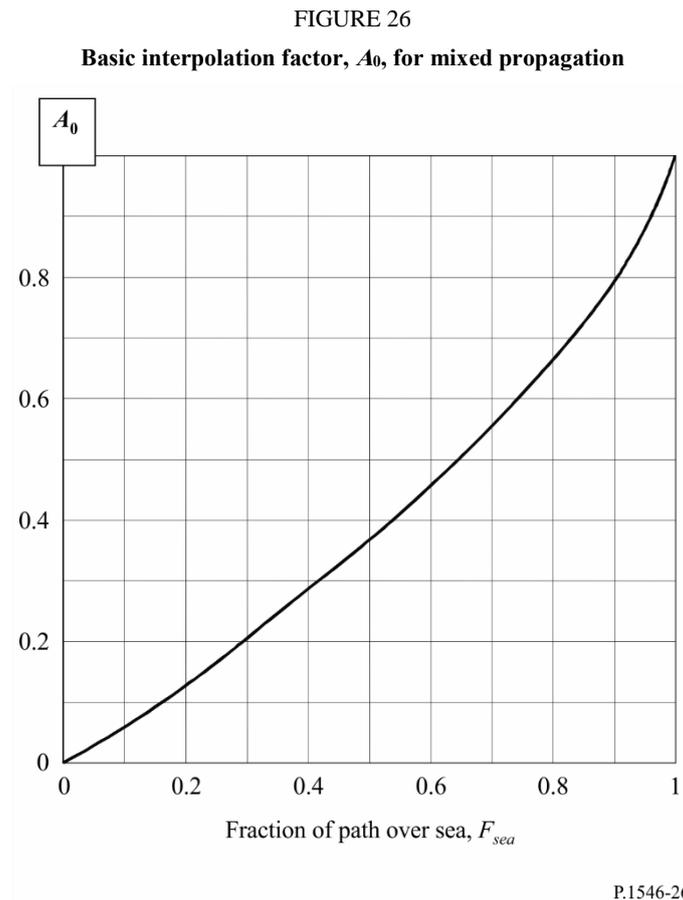
The interpolation factor¹, A , is given by equations (18)-(20), but with the fraction of path over sea, F_{sea} , used in Fig. 26 and equation (18), given by:

$$F_{sea} = \frac{d_{sT}}{d_{total}} \quad (25)$$

and Δ , used in equation (20) is now given by:

$$\Delta = \sum_{n=1}^{N_s} E_{sn}(d_{total}) \frac{d_{sn}}{d_{sT}} - \sum_{m=1}^{M_l} E_{lm}(d_{total}) \frac{d_{lm}}{d_{lT}} \quad (26)$$

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



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

¹ 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.

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 equal to the greater of the representative of the height of the ground cover surrounding the receiving/mobile antenna, R_2 , and 10 m. Examples of reference heights are 15 m for an urban area, 20 m for a dense urban area and 10 m for a suburban area. For sea paths the notional value of R_2 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_2' , given by:

$$R_2' = (1000dR_2 - 15h_1)/(1000d - 15) \quad \text{m} \quad (27)$$

where h_1 and R_2 are in units of metres, and horizontal distance d in km. The representative clutter height R_2' is calculated in such way, that it represents the reference point of height for a receiver which is situated 15 m behind the clutter encountering grazing incidence of the ray from the transmitter.

The representative height R_2' represents a reference height at which a receiver would encounter grazing incident ($v = 0$).

Note that for $h_1 < 6.5d + R_2$, $R_2' \approx R_2$.

The value of R_2' 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:

$$\text{Correction} = 6.03 - J(v) \quad \text{dB} \quad \text{for } h_2 < R_2' \quad (28a)$$

$$= K_{h_2} \log(h_2 / R_2') \quad \text{dB} \quad \text{for } h_2 \geq R_2' \quad (28b)$$

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

and:

$$v = K_{nu} \sqrt{h_{dif2} \theta_{clut2}} \quad (28c)$$

$$h_{dif2} = R_2' - h_2 \quad \text{m} \quad (28d)$$

$$\theta_{clut2} = \arctan(h_{dif2} / 27) \quad \text{degrees} \quad (28e)$$

$$K_{h_2} = 3.2 + 6.2 \log(f) \quad (28f)$$

$$K_{nu} = 0.0108 \sqrt{f} \quad (28g)$$

f : frequency (MHz).

In cases in an urban environment where R_2' is less than 10 m, the correction given by equation (28a) or (28b) should be reduced by $K_{h_2} \log(10/R_2')$.

Where the receiving/mobile antenna is on land in a rural or open environment the correction is given by equation (28b) for all values of h_2 with R_2' 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 (28b) with R_2' 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 § 18.

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 § 18.

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 (28b) with R_2' 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:

$$\text{Correction} = 0.0 \text{ dB} \quad \text{for} \quad d \leq d_{h_2} \quad (29a)$$

$$= C_{10} \log(d / d_{h_2}) / \log(d_{10} / d_{h_2}) \text{ dB} \quad \text{for} \quad d_{h_2} < d < d_{10} \quad (29b)$$

where:

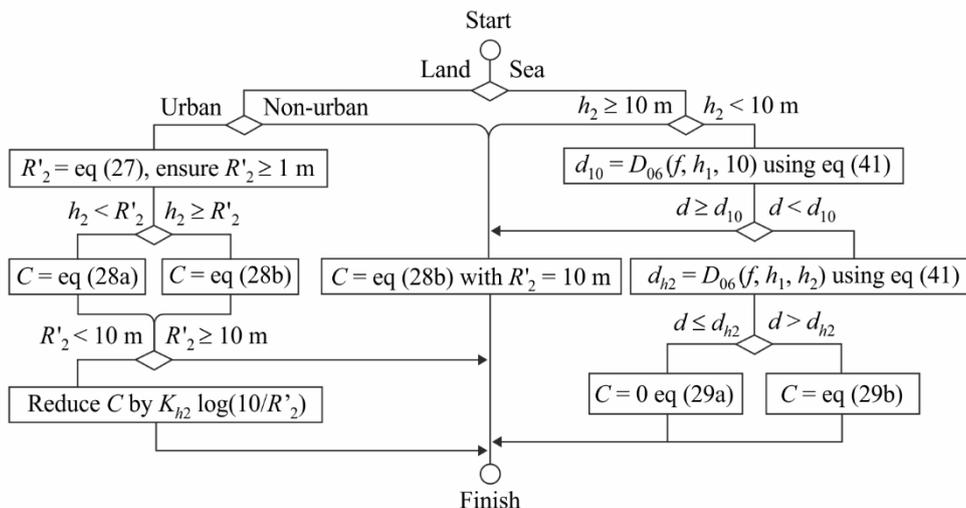
- C_{10} : correction for the required value of h_2 at distance d_{10} using equation (28b) with R_2' set to 10 m
- d_{10} : distance at which the path just has 0.6 Fresnel clearance for $h_2 = 10$ m calculated as $D_{06}(f, h_1, 10)$ as given in § 18
- d_{h_2} : distance at which the path just has 0.6 Fresnel clearance for the required value of h_2 calculated as $D_{06}(f, h_1, h_2)$ as given in § 18.

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

Flowchart for receiver/mobile antenna height correction



10 Cluttered transmitter correction

This correction does not apply for an open/uncluttered transmitter. The correction should be used in all other cases, including when the antenna is above the clutter height. The correction is zero when the terminal is higher than a frequency-dependent clearance height above the clutter.

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

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

and:

$$v = K_{nu} \sqrt{h_{dif1} \theta_{clut1}} \quad \text{for } R_1 \geq h_a \quad (30b)$$

$$= -K_{nu} \sqrt{h_{dif1} \theta_{clut1}} \quad \text{otherwise} \quad (30c)$$

$$h_{dif1} = h_a - R_1 \quad \text{m} \quad (30d)$$

$$\theta_{clut1} = \arctan(h_{dif1} / 27) \quad \text{degrees} \quad (30e)$$

$$K_{nu} = 0.0108 \sqrt{f} \quad (30f)$$

f : frequency (MHz).

And R_1 is the height of clutter, m above ground level, in the vicinity of the transmitting/base terminal.

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 θ_{tca} is given by:

$$\theta_{tca} = \theta \quad \text{degrees} \quad (31)$$

where θ 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 θ should not take Earth curvature into account. θ_{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:

$$\text{Correction} = J(v') - J(v) \quad \text{dB} \quad (32a)$$

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

$$v' = 0.036 \sqrt{f} \quad (32b)$$

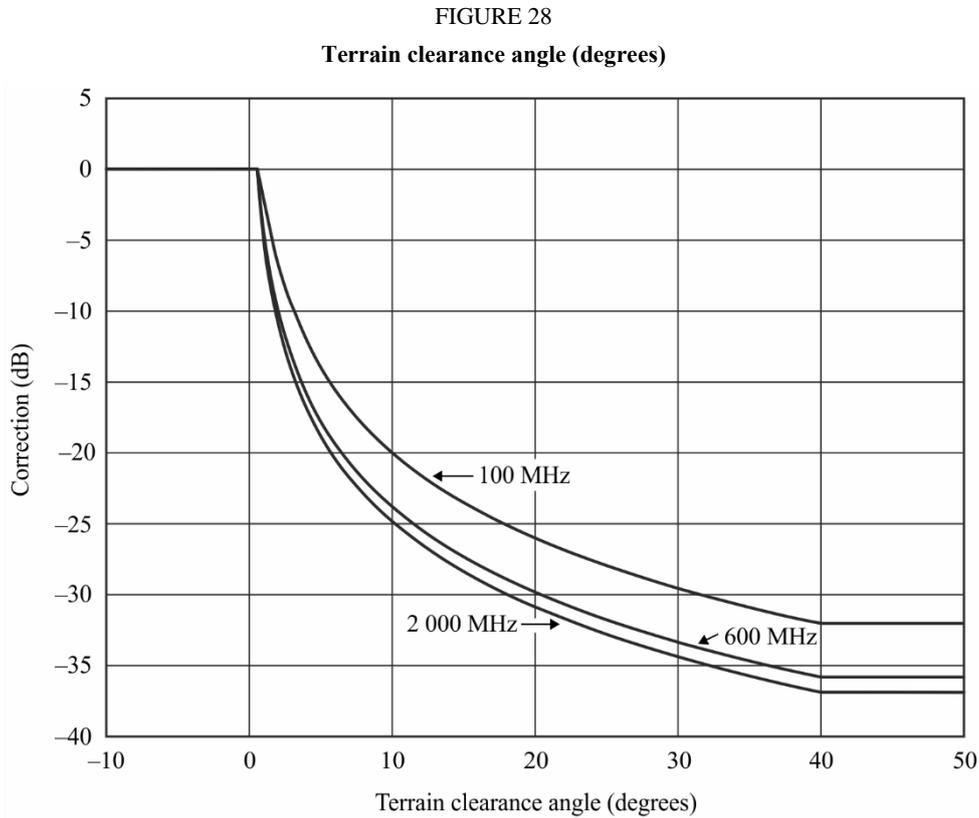
$$v = 0.065 \theta_{tca} \sqrt{f} \quad (32c)$$

θ_{tca} : 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.



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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 specific 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, basic transmission 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. 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.

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.

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.

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.

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. This definition will be appropriate when applying Annex 5, § 3.1.1 in the implementation of this recommendation. A second definition relates to the variability of field strength over a small area, typically represented by a square with a side of 50 m to 1 km, this definition is appropriate when using terrain information in the calculation of h_l , as described in Annex 5, § 3.1.2.

Extensive data analysis suggests that the distribution of local mean field strength due to ground cover variations 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:

$$E(q) = E(\text{median}) + Q_i(q/100)\sigma_L \quad \text{dB}(\mu\text{V/m}) \quad (33)$$

where:

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

σ_L : standard deviation of the Gaussian distribution of the local means in the study area.

An approximation to function $Q_i(x)$ is given in § 16 below.

Values of standard deviation are dependent on the prediction resolution and frequency, and empirical studies have shown a spread. In the case where terrain data is being used and the variation over a small area is required representative values of σ_L are given by equation (34). The representative values relate to the 50th percentile of the cumulative distributions of measured standard deviation of location variability.

$$\sigma_L = \left(\frac{0.0024f}{1000} + 0.52 \right) w_a^{0.28} \quad \text{dB} \quad (34)$$

where:

f : required frequency (MHz)

w_a : prediction resolution (m).

The prediction resolution is the width of the square area over which the variability applies.

When using this Recommendation without terrain information the variation across the service area might be a more appropriate measure of σ_L . In this case no dependency on frequency is found however the environment type will impact the standard deviation of location variability values. Representative values of σ_L are 8, 10 and 12 dB for urban, suburban and open areas respectively.

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 values given in Table 2 have been found appropriate for the planning of digital terrestrial television (DTT) services, this was found to be equivalent to the 93rd percentile of the measurement CDF for rooftop height antenna for a 100×100 m area.

TABLE 2
Values of variability used in certain planning situations

	Standard deviation (dB)		
	100 MHz	600 MHz	2 000 MHz
Broadcasting, DTT	5.5	5.5	5.5

13 Limiting field due to 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, an estimate of the field due to tropospheric scattering should be calculated using the following procedure. This estimate can then be used as a ‘floor’ to the overall prediction of the field strength (see Annex 6 step 13).

Calculate the path scattering angle in degrees, θ_s , using:

$$\theta_s = \frac{180d}{\pi ka} + \theta_{eff} + \theta \quad \text{degrees} \quad (35)$$

where:

- θ_{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)
- θ : 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 θ_s is less than zero, set θ_s equal to zero.

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

$$E_{ts} = 24.4 - 20 \log(d) - 10 \theta_s - L_f + 0.15N_0 + G_t \quad \text{dB}(\mu\text{V/m}) \quad (36)$$

where:

$$L_f: \text{ frequency-dependent loss} \\ = 5 \log(f) - 2.5(\log(f) - 3.3)^2 \quad (36a)$$

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

$$G_t: \text{ time-dependent enhancement} \\ = 10.1(-\log(0.02t))^{0.7} \quad (36b)$$

d : path length or required distance (km)

f : required frequency (MHz)

t : required percentage of time.

14 Antenna-height difference

A correction is required to take account of the difference in height between the two antennas.

This correction is calculated as follows.

$$\text{Correction} = 20 \log \left(\frac{d}{d_{slope}} \right) \quad \text{dB} \quad (37)$$

where d is the horizontal distance and the slope distance, d_{slope} , is given as follows.

Where terrain information is available, use:

$$d_{slope} = \sqrt{d^2 + 10^{-6} [(h_a + h_{tter}) - (h_2 + h_{rter})]^2} \quad \text{km} \quad (37a)$$

Where terrain information is not available, use:

$$d_{slope} = \sqrt{d^2 + 10^{-6} (h_a - h_2)^2} \quad \text{km} \quad (37b)$$

and h_{tter} and h_{rter} are the terrain heights in metres above sea level at the transmitter/base and receiving/mobile terminals respectively.

The hypotenuse geometry implied by equation (37a) is unrealistic for paths long enough for Earth curvature to be significant, but for such long paths the associated error is negligible. Although the correction given by equation (37) is very small except for short paths and high values of h_1 , it is recommended that it is used in all cases to avoid making an arbitrary decision as to precision.

15 Distances less than 1 km

The foregoing §§ 1 to 14 describe the method for obtaining field strengths from the curve families for horizontal distances from 1 km to 1 000 km. This process includes interpolation or extrapolation and various corrections. If the required horizontal distance is 1 km or greater, no further calculation is needed.

For paths less than 1 km the model is extended to arbitrarily short horizontal distances as follows:

If the horizontal distance is less than or equal to 0.04 km the field strength, E , is given by:

$$E = 106.9 - 20 \log(d_{slope}) \quad \text{dB}(\mu\text{V/m}) \quad (38a)$$

Otherwise:

$$E = E_{inf} + (E_{sup} - E_{inf}) \log(d_{slope}/d_{inf}) / \log(d_{sup}/d_{inf}) \quad \text{dB}(\mu\text{V/m}) \quad (38b)$$

where:

d_{slope} : slope distance given by equation (37a) or (37b) for the required horizontal distance d

d_{inf} : slope distance given by equation (37a) or (37b) for $d = 0.04$ km

d_{sup} : slope distance given by equation (37a) or (37b) for $d = 1$ km

E_{inf} : $106.9 - 20 \log(d_{inf})$

E_{sup} : field strength given by §§ 1 to 14 for $d = 1$ km.

This extension to arbitrarily short horizontal distance is based on the assumption that as a path decreases in length below 1 km there is an increasing probability that a lower-loss path will exist passing around obstacles rather than over them. For paths of 0.04 km horizontal distance or shorter,

it is assumed that line-of-sight with full Fresnel clearance exists between the terminals, and the field strength is calculated as the free-space value based on the slope distance.

If these assumptions do not fit the required short-range scenario, appropriate adjustments should be made to account for effects such as street-canyon propagation, building entry, indoor sections of path, or body effects.

This extension to short distances can allow the path to have a steep inclination, or even be vertical if $h_a > h_2$. It is important to note that the predicted field strength does not take account of the vertical radiation pattern of the transmitting/base antenna. The field strength corresponds to 1 kW e.r.p. in the direction of radiation.

16 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 $0.01 \leq x \leq 0.99$:

$$Q_i(x) = T(x) - \xi(x) \quad \text{if } x \leq 0.5 \quad (39a)$$

$$Q_i(x) = -\{T(1-x) - \xi(1-x)\} \quad \text{if } x > 0.5 \quad (39b)$$

where:

$$T(x) = \sqrt{[-2 \ln(x)]} \quad (39c)$$

$$\xi(x) = \frac{[(C_2 \cdot T(x) + C_1) \cdot T(x)] + C_0}{[(D_3 \cdot T(x) + D_2) \cdot T(x) + D_1] \cdot T(x) + 1} \quad (39d)$$

$$C_0 = 2.515517$$

$$C_1 = 0.802853$$

$$C_2 = 0.010328$$

$$D_1 = 1.432788$$

$$D_2 = 0.189269$$

$$D_3 = 0.001308$$

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

TABLE 3 (end)

$q\%$	$Q_i(q/100)$	$q\%$	$Q_i(q/100)$	$q\%$	$Q_i(q/100)$	$q\%$	$Q_i(q/100)$
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		

17 Equivalent basic transmission loss

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

$$L_b = 139.3 - E + 20 \log f \quad \text{dB} \quad (40)$$

where:

L_b : basic transmission loss (dB)

E : field strength (dB(μ V/m)) for 1 kW e.r.p.

f : frequency (MHz).

18 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:

$$D_{06} = \frac{D_f \cdot D_h}{D_f + D_h} \quad \text{km} \quad (41)$$

where:

$$D_f: \text{ frequency-dependent term} \\ = 0.0000389 f h_1 h_2 \quad \text{km} \quad (41a)$$

$$D_h: \text{ asymptotic term defined by horizon distances} \\ = 4.1(\sqrt{h_1} + \sqrt{h_2}) \quad \text{km} \quad (41b)$$

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 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	Definition	Limits
f (MHz)	Operating frequency	30-4 000 MHz
d (km)	Horizontal path length	Not greater than 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	Greater than 1
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
h_2 (m)	Receiving/mobile antenna height above ground. Defined in Annex 1, § 10	Land – Not less than 1 m, and less than 3 000 m Sea – Not less than 3 m, and less than 3 000 m

TABLE 4 (*end*)

Parameter	Definition	Limits
R_1 (m)	Representative clutter height (around transmitter)	None
R_2 (m)	Representative clutter height (around receiver)	None
θ_{ica} (degrees)	Terrain clearance angle	0.55° to 40°
θ_{eff} θ_{eff1} θ_{eff2} (degrees)	Transmitter/base effective terrain clearance angles. Annex 5, § 9	Must be positive

If the required horizontal distance is 0.04 km or less, start at Step 17. If the required horizontal distance is greater than 0.04 km and less than 1 km, steps 1 to 16 should be followed with d set to 1 km, after which the remaining steps should be followed with d set to the required value. Otherwise all steps should be followed with d set to the required value.

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 4 000 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_2 , 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_2 , 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 take the maximum of E and E_{ts} .

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

Step 15: If there is clutter around the transmitting/base terminal, even if at a lower height above ground than the antenna, correct for its effect using the method given in Annex 5, § 10.

Step 16: Apply the slope-path correction given in Annex 5, § 14.

Step 17: Annex 5, § 15, gives the method for paths less than 1 km. As noted immediately before Step 1 above, it may first be necessary to follow Steps 1 to 16 for $d = 1$ km.

Step 18: 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 19: 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:

$$E_{max} = E_{fs} + d_s E_{se} / d_{total} \quad \text{dB}(\mu\text{V/m}) \quad (42)$$

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 20: If required, convert field strength to equivalent basic transmission loss for the path using the method given in Annex 5, § 17.

Annex 7

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:

$$\text{For fields exceeded for 50\% time: } dN_0 = -43.3 \quad \text{N-units/km} \quad (43a)$$

$$\text{For fields exceeded for 10\% time: } dN_0 = -141.9 \quad \text{N-units/km} \quad (43b)$$

$$\text{For fields exceeded for 1\% time: } dN_0 = -301.3 \quad \text{N-units/km} \quad (43c)$$

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

$$\Delta N = dN_0 - dN \quad (44)$$

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 (43).

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

$$\delta E_{max} = 0.007(-301.3 - dN) \{1 - \exp(-d/50)\} \exp(-d/6000) \quad \text{dB} \quad (45)$$

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:

$$K = 14.94 - 6.693 \times 10^{-6} (1494 - \Delta N)^2 \quad \Delta N > 0 \quad (46a)$$

$$= 0.08 \Delta N \quad \Delta N \leq 0 \quad (46b)$$

For the lowest curve in the family to be adjusted, that is for $h_1 = 10$ m, add an adjustment, δE_1 , given by:

$$\delta E_1 = K \{1 - \exp(-d/50)\} \exp(-d/6000) \quad \text{dB} \quad (47)$$

If necessary, the value of δE_1 must be limited as follows:

- δE_1 must be limited such that the adjusted field strength does not exceed the adjusted maximum field strength.
- If ΔN is greater than zero, δE_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 ΔN 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:

$$E'_n = E'_1 + (E_n - E_1) (E'_{max} - E'_1) / (E_{max} - E_1) \quad (48)$$

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.

Annex 8

Comparison with the Okumura-Hata method

The Okumura-Hata method is given by:

$$E = 69.82 - 6.16 \log f + 13.82 \log H_1 + a(H_2) - (44.9 - 6.55 \log H_1)(\log d)^b \quad (49)$$

where:

E : field strength (dB(μ 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)

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

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

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

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, $R = 15$.
