SECTION 5G: PROPAGATION DATA REQUIRED FOR THE EVALUATION OF INTERFERENCE: SPACE AND TERRESTRIAL SYSTEMS

RECOMMENDATION ITU-R PN.452-6

PREDICTION PROCEDURE FOR THE EVALUATION OF MICROWAVE INTERFERENCE BETWEEN STATIONS ON THE SURFACE OF THE EARTH AT FREQUENCIES ABOVE ABOUT 0.7 GHz

(Question ITU-R 208/3)

(1970-1974-1978-1982-1986-1992-1994)

The ITU Radiocommunication Assembly,

considering

a) that due to congestion of the radio spectrum, frequency bands must be shared between different terrestrial services, between systems in the same service and between systems in the terrestrial and Earth-space services;

b) that for the satisfactory coexistence of systems sharing the same frequency bands, interference propagation prediction procedures are needed that are accurate and reliable in operation and acceptable to all parties concerned;

c) that interference propagation predictions are required to meet "worst-month" performance and availability objectives;

d) that prediction methods are required for application to all types of path in all areas of the world,

recommends

1. that, for frequencies above about 0.7 GHz, the microwave interference prediction procedure given in Annex 1 be used for the evaluation of the available propagation loss in interference calculations between stations on the surface of the Earth.

ANNEX 1

1. Introduction

Congestion of the radio-frequency spectrum has made necessary the sharing of many of the microwave frequency bands between different radio services, and between the different operators of similar radio services. In order to ensure the satisfactory coexistence of the terrestrial and Earth-space systems involved, it is important to be able to predict with reasonable accuracy the levels of interference that might exist between them, using prediction procedures and models which are acceptable to all parties concerned, and which have demonstrated accuracy and reliability.

Many types and combinations of interference path may exist between stations on the surface of the Earth and between these stations and stations in space, and prediction methods are required for each scenario. This Annex addresses one of the more important sets of interference problems, i.e., those situations where there is a potential for interference between microwave radio stations located on the surface of the Earth.

The prediction procedure detailed below is appropriate to terrestrial microwave link stations and satellite earth stations operating in the frequency range of about 0.7 GHz to 30 GHz. The method includes a comprehensive set of propagation models which ensure that the predictions embrace all the significant propagation mechanisms that can arise. Techniques for analysing the radio-meteorological and topographical features of the path are provided so that it is possible to generate a prediction for any practical type of interference path.

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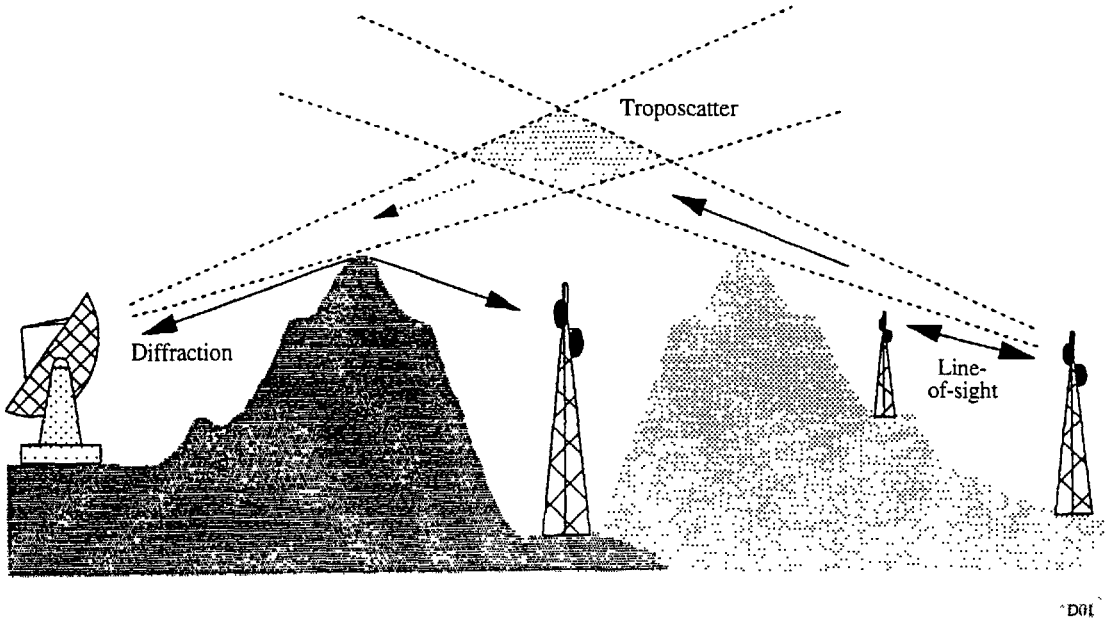
2. Interference propagation mechanisms

Microwave interference propagation may arise through a range of propagation mechanisms whose individual dominance depends on many factors, including climate, radio frequency, time percentage of interest, distance and path topography. At any one time a single mechanism or more than one may occur.

The eight principal interference propagation mechanisms are outlined here, of which the first four may be regarded as long-term, or continuous, interference mechanisms (Fig. 1), and the remaining four as short-term, or anomalous, mechanisms (Fig. 2) usually generating much higher interfering signal levels.

FIGURE 1

Long-term interference propagation mechanisms



2.1 Line-of-sight

The most straightforward interference propagation mechanism is line-of-sight under well-mixed atmospheric conditions. An additional complexity can, however, come into play when sub-path diffraction causes an increase in signal level.

2.2 Diffraction

The accuracy to which this mechanism can be modelled often determines the density of microwave systems that can be achieved in a given area. The diffraction prediction capability must have sufficient utility to cover smooth-earth, discrete obstacle and irregular terrain situations.

2.3 Tropospheric scatter

This mechanism defines the "background" interference level for longer paths (e.g., 100-150 km). The prediction requirement for this mode in the interference context is somewhat different from that needed for troposcatter link design as it is time percentages below 50% that are of interest, often on paths with a highly asymmetrical geometry and with the common volumes being generated by antenna side lobes.

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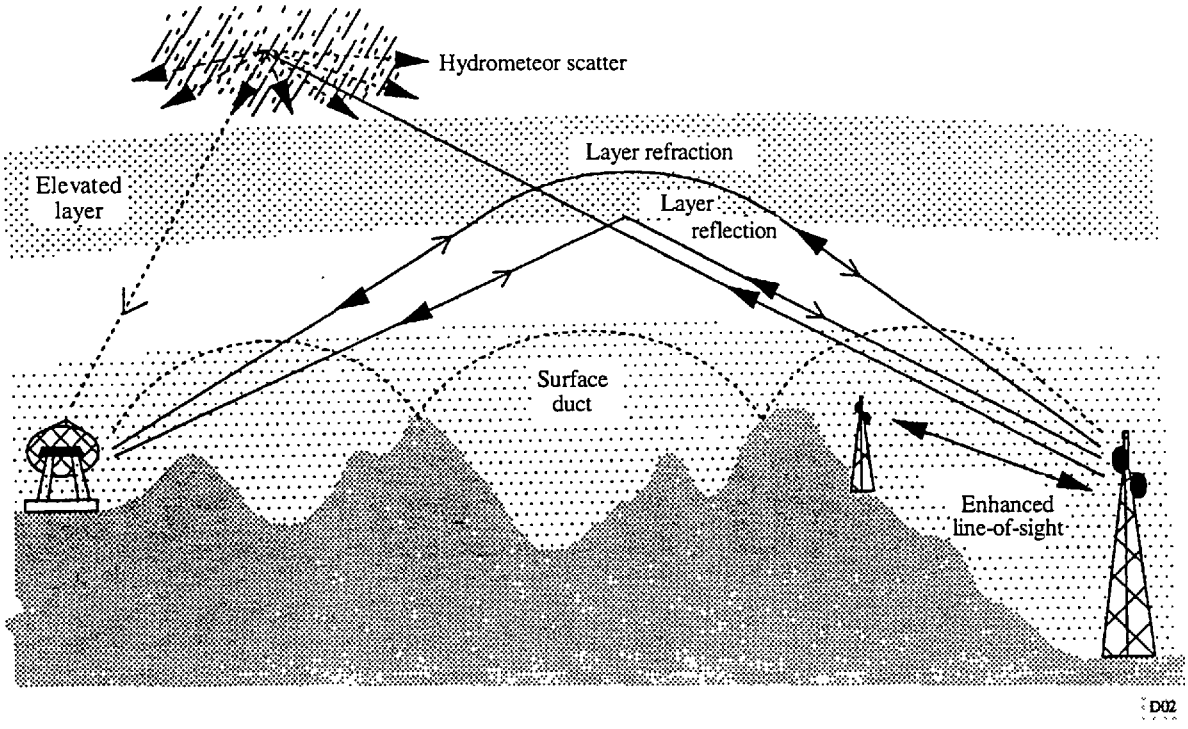
FIGURE 2

Short-term (enhanced) propagation mechanisms



2.4 *Scatter from terrain and buildings* (not illustrated in Fig. 1)

This has not hitherto been a problem, but may become important in the future if crossing paths and high-density networks of paths become more commonplace. This mechanism is not currently covered by this prediction procedure.

2.5 *Enhanced line-of-sight*

The interference propagation mechanism of unobstructed transmission on line-of-sight paths may sometimes have levels raised by multipath and focusing effects.

2.6 *Surface super-refraction and ducting*

This is the most important short-term interference mechanism over water and in flat coastal land areas.

2.7 *Elevated layer reflection and refraction*

The treatment of reflection and/or refraction from layers at heights up to a few hundred metres is of major importance as these mechanisms enable signals to bypass the diffraction loss of the terrain very effectively under favourable path geometry situations.

2.8 Hydrometeor scatter

Hydrometeor scatter is particularly important as a possible source of interference because it may act virtually omni-directionally .

A basic problem in interference prediction (which is indeed common to all tropospheric prediction procedures) is the difficulty of providing a unified consistent set of practical methods covering a wide range of distances and time percentages; i.e., for the real atmosphere in which the statistics of one mechanism merge gradually into another as meteorological and/or path conditions change. Especially in these transitional regions, a given level of signal may occur

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for a time percentage which is the sum of those in different mechanisms. The approach in this procedure has been deliberately to keep separate the prediction of interference levels from the different propagation mechanisms up to the point where they can be combined into an overall prediction for the path. This is especially the case for the two somewhat different circumstances of clear-air and hydrometeor scatter conditions.

3. Clear-air interference prediction

3.1 Global and European procedures

The text below provides two complementary versions of a comprehensive clear-air interference prediction procedure which takes into account the clear-air propagation mechanisms outlined in § 2 above. The first version, the "global" procedure (§ 3.2), can be applied (for all practical purposes) on a world-wide basis, and uses radio-meteorological data to describe the location variability of interference propagation conditions. The second version, the "European" procedure (§ 3.3) offers improved precision for North-West Europe, from where a significant amount of measured data has allowed more accurate determination of propagation characteristics based on land, sea and coastal zone concepts. The two procedures are essentially the same apart from the method of defining the radio-meteorological influences affecting the anomalous propagation conditions on the path.

The procedures below are intended for computer implementation, although it is possible to hand-work the important clear-air calculations for individual paths if required. Maps are used to provide essential input data, but the intention is that these be realized as simple databases for use by computer software. Appendix 1, which contains the maps, also suggests one convenient method of creating suitable databases.

3.2 Deriving a prediction using the global procedure

3.2.1 Outline of the procedure

The global procedure allows average year or (quasi) worst-month predictions to be derived for any path bounded by 80° North and 70° South. The North-South limits are imposed by the current availability of radio-meteorological data. The procedure embraces all the clear-air propagation mechanisms mentioned in § 2 above (with the exception of terrain and building scatter). The variations in propagation conditions around the world are described by means of maps of long and short term radio refractive index conditions. (The resolution and accuracy of the data in these maps is currently being improved for areas where better data have become available since the original work.)

There are seven stages to deriving a prediction using the global method:

Step 1: Decide whether an average year or worst-month prediction is required.

Step 2: Assemble the basic input data.

Step 3: Derive the annual or worst-month radio-meteorological data from the maps provided.

Step 4: Analyse the path profile, and classify the path according to the path geometry.

Step 5: Identify which individual propagation models need to be invoked.

Step 6: Calculate the individual propagation predictions using each of the models identified in Step 5.

Step 7: Combine the individual predictions to give the overall statistics.

3.2.2 Choice of average year or worst-month prediction

The decision as to whether annual or "worst-month" predictions are required is dictated by the quality (i.e., performance and availability) objectives of the interfered-with radio system at the receiving end of the interference path. As interference is often a bi-directional problem, two such sets of quality objectives may need to be evaluated in order to determine the worst-case situation upon which the prediction needs to be based. In the majority of cases the quality objectives will be couched in terms of a percentage "of any month", and hence worst-month data will be needed.

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True worst-month data can only be provided when there exists an extensive database of long-term radio measurements (ideally 10 years or more). No such database exists for interference propagation data from around the world, and thus the global method has to rely on quasi worst-month data derived from long-term meteorological measurements, on the assumption that reliable relationships exist between the observed meteorological conditions and the actual propagation conditions. However, this approximation of the worst-month situation has proved realistic in tests against such measured data as are available, and provides prediction results far closer to operational requirements than have previously been available.

3.2.3 *Assembling the input data*

The basic input data required for the global procedure is given in Table 1:

TABLE 1

Basic input data

Parameter	Preferred resolution	Description
f	0.01 GHz	Frequency (GHz)
p	0.001%	Required time percentage(s) for which the calculated basic transmission loss is not exceeded
φ_t, φ_r	0.001°	Latitude of station (degrees)
ψ_t, ψ_r	0.001°	Longitude of station (degrees)
h_{tg}, h_{rg}	1 m	Antenna centre height above ground level (m)
G_t, G_r	0.1 dBi	Antenna gain in the direction of the horizon along the great-circle interference path (dBi)

It should be noted that, for the interfering and interfered-with stations:

t: interferer

r: interfered-with.

In addition, where the path is partly over the sea or other large areas of water, certain additional information about the great-circle interference path needs to be determined, as indicated in Table 2. All other information required to complete the prediction is derived from these basic data during the execution of the procedure.

3.2.4 *Radio-meteorological data for the path*

The global model uses two radio-meteorological parameters to describe the variability of background and anomalous propagation conditions at the different locations around the world.

- ΔN, the average radio-refractive index lapse-rate through the first 1 km of the atmosphere, provides the data upon which the appropriate effective earth radius can be based for path profile and diffraction obstacle analysis. Figures 5 and 6, respectively, provide world maps of average annual values of ΔN and maximum monthly mean values of ΔN (for worst month prediction).

- The parameter β_0% is the time percentage for which super-refractive lapse-rates with gradients of modulus exceeding 100 N-units/km can be expected in the lower atmosphere, and is used as a measure of the incidence of fully developed anomalous propagation in the area under consideration. Figures 7 and 8, respectively, provide the annual and maximum monthly mean time percentages, β_0% relevant to these anomalous propagation conditions.

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TABLE 2

Additional input data required for paths with one or more sea sections

Parameter	Preferred resolution	Description
d_b	1 km	Aggregate length of the path sections over water (km)
ω	–	Fraction of the total path over water: $\omega = d_b/d$ (1) where d is the great-circle distance (km) calculated using equation (29) in Appendix 2. For totally overland paths $\omega = 0$
d_{ct} (1)	0.1 km	Distance from the first terminal (the interference source) to the coast along the great-circle interference path (km)
d_{cr} (1)	0.1 km	Corresponding distance for the second (interfered-with) station (km)

(1) The exact values of d_{ct} and d_{cr} are only of importance if in the range 0 km < d_{ct}; $d_{cr} \leq 3$ km. If, in either or both cases, the distances are obviously in excess of 3 km then it is only necessary to note the > 3 km condition for future reference. Few interference paths will in fact need detailed evaluation of these two parameters.

The correct input data for the prediction models is given by the average of the path-end and path centre values of ΔN and β_0% appropriate to the path in question from Figs. 5 and 7 for any (average year) or Figs. 6 and 8 (for the worst month) as decided in the procedural step in § 3.2.2. However, in areas where the values are reasonably constant the path centre value alone can safely be used.

Using the radio-meteorological data, the median effective earth radius factor k_{50} for the path can be determined:

$$k_{50} = \frac{157}{157 - \Delta N} \tag{2}$$

(Note that ΔN is considered to be a positive quantity in this procedure.)

When diffraction calculations need to be undertaken (see Table 4 for conditions), the basic transmission loss variability with time percentage due to the diffraction propagation mechanism is assumed to be the result of changes in bulk atmospheric radio refractivity lapse rate. As the time percentage, p, reduces, the effective earth radius factor $k(p)$ is assumed to increase according to the function:

$$k(p) = k_{50} + (5 - k_{50}) \frac{1.7 - \log p}{1.7 - \log \beta_0} \tag{2a}$$

Note that this expression is only valid for $p\% \leq 50\%$.

Using the value of k_{50} found from equation (2), and assuming a true earth radius of 6 375 km, the median value of effective earth radius a_e can be determined:

$$a_e = 6375 \cdot k_{50} \quad \text{km} \tag{3}$$

Once again, under the specific conditions which make necessary the diffraction calculations, a time-varying value of effective earth radius, $a(p)$, is needed during the derivation of the diffraction geometry for each required time percentage:

$$a(p) = 6375 \cdot k(p) \quad \text{km} \tag{3a}$$

3.2.5 Calculating predictions for appropriate individual mechanisms

There are four clear-air propagation models provided within this procedure, each dealing with a particular propagation mechanism. These are summarized in Table 3.

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TABLE 3

Propagation models

Propagation mechanisms	Text section
Line-of-sight (including small time percentage signal enhancement due to multipath and focusing effects)	4.2
Diffraction (embracing irregular terrain, smooth-Earth, and sub-path effects)	4.3
Tropospheric scatter	4.4
Ducting/layer reflection	4.5

Depending on the path characteristics, calculations need to be performed using one or more of these models. The type of path must be determined using a path profile.

3.2.6 Analysis of the path profile

Values for a number of path-related parameters must be found via an initial analysis of the path profile for $p = 50\%$. The main information on the derivation, construction and analysis of the path profile is given in Appendix 2.

Having analysed the profile under median atmospheric conditions according to the method in Appendix 2, the path will have been classified into one of the three geometrical categories indicated in Table 4. This classification then applies for the remainder of the procedure.

TABLE 4

Interference path classifications and propagation model requirements

Classification	Models required (with conditions)
Line-of-sight with first Fresnel zone clearance	Line-of-sight
Line-of-sight with sub-path diffraction(1)	Line-of-sight; diffraction
Trans-horizon	Diffraction ($d \leq 200$ km and $\beta_0 < 50\%$) Troposcatter ($\theta \geq 8$ mrad) Ducting/layer reflection ($d > 20$ km)

(1) Sub-path diffraction is defined by a terrain incursion into the first Fresnel zone.

The remaining path-related parameters necessary for the calculations, as indicated in Table 5, will also have been determined from the path profile.

3.2.7 Calculation of individual propagation predictions

Table 4 indicates, for each type of path, the propagation models that are appropriate, and the conditions under which each should be exercised, in order to derive the correct overall prediction. The necessary equations for these individual mechanism predictions are to be found in the text sections indicated in Table 3.

In order to build an overall prediction, the individual propagation mechanism predictions must be calculated and combined (see § 3.2.8) for each time percentage $p\%$ for which a prediction is required.

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TABLE 5

Output parameters required from the path profile analysis

Path type	Parameter	Description
All	d	Great-circle path distance (km)
Trans-horizon	d_{lt}, d_{lr}	Distance from the transmit and receive antennas to their respective horizons (km)
Trans-horizon	θ_t, θ_r	Transmit and receive horizon elevation angles respectively (mrad)
Trans-horizon	θ	Path angular distance (mrad)
Trans-horizon	h_{te}, h_{re}	Effective heights(1) of antennas above the terrain (m)
Trans-horizon	h_m	Terrain roughness(1) (m)

(1) See Appendix 2 for definitions.

Note 1 – Other profile parameters required for evaluation of diffraction over a line-of-sight path with subpath obstructions, or for a trans-horizon path, are described in Recommendation ITU-R PN.526.

3.2.8 *Determine overall prediction*

The method of combining the individual mechanism predictions into an overall path prediction depends on the type of path, as shown in Table 6.

Once this has been completed for all the required time percentages, the prediction is complete.

Note that discontinuities in the model have been found to be possible for paths of approximately 20 km distance and 8 mrad angular distance for path losses not exceeded for 0.001% time.

TABLE 6

Methods of deriving overall predictions

Path type	Action required
Line-of-sight	None; the correct overall prediction is that supplied by the line-of-sight model
Line-of-sight with sub-path diffraction	The prediction is obtained by summing the losses given by the line-of-sight and (sub-path) diffraction models, i.e.: $L_b(p) = L_{b0}(p) + L_{ds}(p)$ dB (4) where: $L_{b0}(p)$: predicted basic transmission loss not exceeded for p% of time given by the line-of-sight model $L_{ds}(p)$: prediction for p% of time given by the *sub-path* diffraction loss element of the diffraction model
Trans-horizon	The overall prediction can be obtained for each time percentage by adopting the lowest basic transmission loss from the propagation models exercised, however, a smoother transition between mechanisms, better emulating what is observed in nature, can be obtained by applying the following ancillary algorithm: $L_b(p) = -5 \log \left(10^{-0.2L_{bs}} + 10^{-0.2L_{bd}} + 10^{-0.2L_{ba}}\right)$ dB (5) where: $L_{bs}(p)$, $L_{bd}(p)$ and $L_{ba}(p)$: individual predicted basic transmission loss for p% of time given by the troposcatter, diffraction and ducting/layer reflection propagation models respectively. *Note 1* – Where a model has not been proposed for a path (because the conditions given in Table 4 were not met), the appropriate term should be omitted from equation (5).

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3.3 *Deriving a prediction using the "European" procedure*

3.3.1 *Outline of the European procedure*

The "European" version of the procedure is based on a large amount of measured data from North-West Europe. Until future versions of the maps of the radio-meteorological data used for the global procedure can provide a similar resolution and accuracy (particularly for worst month), this European version of the procedure offers increased prediction precision for interference paths within the area bounded (approximately) by 12° W, 20° E, 45° N and 70° N.

The seven stages to deriving a prediction described for the global procedure (§ 3.2.1) still apply in this case. However two cases (Steps 1 and 3 relating to radio-meteorology) are modified for the European version. The straightforward changes are described in § 3.3.2 and 3.3.4.

3.3.2 *Choice of average year or worst-month predictions* (replaces procedure of § 3.2.2 of global method)

The European version basically predicts the annual distribution of basic transmission loss. For average year predictions the required values of $p\%$ are used directly in the prediction equations.

Should worst-month data be required (as is probable) the appropriate predictions are derived by converting the required worst-month time percentage(s), $p_m\%$, to the equivalent annual value(s), $p\%$, using an empirically derived model. This worst-month conversion model is based on long term measured statistics from inland, sea and coastal paths in North-West Europe and is known to provide accurate results.

The annual equivalent, $p\%$, of the required worst-month time percentage, $p_m\%$, can be determined from:

$$p = 10^{\left[\frac{\log p_m - 0.186\,\omega - 0.515}{0.816 + 0.078\,\omega}\right]} \quad \% \tag{6}$$

where:

ω: fraction of the path over water.

This value of p is then used for the prediction calculations, the resulting values being appropriate to the required worst-month time percentage, $p_m\%$.

3.3.3 *Assembling the input data*

The basic input information required is identical to that described in § 3.2.3.

3.3.4 *Radio-meteorological data for the path* (modifies § 3.2.4 of the global method)

The European procedure provides empirically derived functions in place of the maps to describe the location variability of the propagation conditions. These functions have also been derived from a substantial database of microwave measurements, and offer a higher confidence level and better spatial resolution than can be provided by the map derived radio-meteorological data.

For the area of Europe covered by this version of the procedure:

$$\Delta N = 39 \quad \text{N-units/km} \tag{7}$$

For the purposes of deriving an accurate value of β_0 the Earth's surface is divided up into three radio-climatic zones as shown in Table 7. A map showing these zones is provided in Fig. 10.

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TABLE 7

European radio-climatic zones

Zone type	Code	Definition
Coastal land	A1	Coastal land and shore areas, i.e. land adjacent to the sea up to an altitude of 100 m relative to mean sea or water level, but limited to a distance of 50 km from the nearest sea area
Inland	A2	All land, other than coastal and shore areas defined as "coastal land" above
Cold sea	B	"Cold" seas, oceans and other large bodies of water (i.e., covering a circle of at least 100 km in diameter[1]) situated at latitudes above 30° (with the exception of the Mediterranean and the Black Sea)

(1) The above cold sea definition correctly implies that only large bodies of water need be considered. However, the inclusion or omission of one or more small lakes, or islands, in the path analysis will not cause significant errors because the model is relatively insensitive to the aggregated zone distances.

To determine the value of the radio-meteorological parameter β_0 it is necessary to determine two additional distances d_{tm} and d_{lm} along the great-circle path based on these zones. These are defined in Table 8.

TABLE 8

Additional path parameters for the European procedure

Parameter	Definition
d_{tm}	The longest continuous land (inland + coastal) section of the great-circle path (km)
d_{lm}	The longest continuous inland section of the great-circle path (km)

Once d_{tm} and d_{lm} are known, β_0% can be determined using:

$$\beta_0 = 7\,\mu_1 \quad \% \tag{8}$$

where:

$$\mu_1 = 10^{(\tau \cdot d_{tm}/40)} \quad \text{for } d_{tm} \leq 40 \text{ km} \tag{8a}$$

$$\mu_1 = 10^{\tau} \quad \text{for } d_{tm} > 40 \text{ km} \tag{8b}$$

$$\tau = -0.493 - 0.352\, d_{lm}/40 \quad \text{for } d_{lm} \leq 40 \text{ km} \tag{8c}$$

$$\tau = -0.845 \quad \text{for } d_{lm} > 40 \text{ km} \tag{8d}$$

4. Clear-air propagation models

4.1 General

The procedures above (both global and European) involve four separate propagation models to provide the components of the overall prediction. These propagation models, which are identical for both versions of the overall procedure, are provided in this section.

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