ANNEX 1

VARIABILITY IN TIME AND WITH LOCATION, PREDICTION ERROR, AND SERVICE PROBABILITY

This annex deals with definitions of satisfactory service for any radio communication system, the variability of service with time and location, and ways of allowing for random errors of prediction. A specified grade of service, g, from a wanted signal in the presence of unwanted signals, and rapid or fine-grained variations of these signal levels with time or receiving location, is assumed to depend only upon whether a required wanted-to-unwanted signal ratio $R_r(g_r)$ is exceeded. If increasing values of available grades represent better grades of service, $R_r(g)$ must increase with g. For any reasonable selection of a receiving system, the probability of power-independent distortion is assumed negligible, or at least minimized.

Let $R(q_T)$ represent the available wanted-to-unwanted signal exceeded for a fraction q_T of a specified period of time. With R_r and q_T fixed, satisfactory service exists if $R(q_T) > R_r$. Data normalized to correspond with the given conditions can be used to predict $R(q_T)$. The service probability, Q, is defined as the expected fraction of normalized data for which $R(q_T) > R_r$.

To avoid accepting an unsatisfactory system, a high service probability is required, while there should be a low service probability for any system that is rejected, other things being equal. Service probability can also be used as a weighting factor in cost-benefit studies or in studying complex netting and multiple access problems. For some applications, such as broadcasting or relay networks with many receivers and/or transmitters, it may be worthwhile to describe variations from location to location statistically instead of examining every possible propagation link. Then the quantity $R(q_T, q_L, Q)$ is defined as the wanted-to-unwanted signal ratio exceeded for at least a fraction q_T of a specified period of time, for a fraction q_L of all receiving antenna locations or propagation paths in a statistically homogeneous area or group, and with a probability Q.

Interference probability is the complement, $P \equiv 1 - Q$, of the service probability. Harmful interference may be said to exist at the antenna terminals of a particular receiving system if the service probability is less than 0.95, i.e., the interference probability is greater than 0.05.

The first section of this annex discusses the time variability of propagation attenuation, the next section describes variability with location, and the last section deals with the statistics of R.

1-1. Variability in Time

1-1.1 Adjustment Function $V(0.5, d_e)$

Adjustments to the calculated long-term reference value A_{cr} of attenuation relative to free space may be required to provide long-term median estimates of $A(0.5)$ for given sets of data. Adjustments described here provide estimates of $A(0.5)$ for specific periods of time and for various climatic regions. Climatic regions are distinguished on the basis of meteorological data as described by the CCIR (1966) and by Rice et al. (1967).

The calculated long-term reference value A_{cr} represents the median attenuation to be expected, assuming minimum monthly mean values of surface refractivity N_s (see sec. 2.1). Therefore, differences are to be expected between the reference value A_{cr} and the long-term median $A(0.5)$ that represents all hours of the year. In the northern temperate zone, for example, minimum monthly mean values of N_s occur during the winter months.

The all-year median attenuation $A(0.5)$ differs from the computed value A_{cr} by an amount $V(0.5)$ dB:

$$A(0.5) = A_{cr} - V(0.5) \text{ dB}. \quad (1.1)$$

This difference $V(0.5)$ between the all-year median attenuation and A_{cr} is shown in figure 1.1 for several climatic regions as a function of an effective distance, d_e, expressed in kilometers.

The effective distance d_e depends on the distance at which diffraction and forward scatter losses are approximately equal over a smooth earth, and on d_{Lo}, which is the sum of the smooth-earth horizon distances for an effective earth's radius $a = 9000$ km. Define θ_{s1} as the angular distance where diffraction and scatter losses are approximately equal over a smooth earth of effective radius $a = 9000$ km. Then,

$$d_{s1} = a\,\theta_{s1} = 65(100/f)^{\frac{1}{3}} \text{ km, and} \quad (1.2a)$$

$$d_{Lo} = 3(\sqrt{2\,h_{e1}} + \sqrt{2\,h_{e2}}) \text{ km}, \quad (1.2b)$$

where f is the frequency in megahertz and $h_{e1,2}$ are the effective antenna heights in meters, defined in section 2.4 (4). The effective distance d_e is then defined as follows:

For $d \leq (d_{Lo} + d_{s1})$ km, $\quad d_e = 130\,d/(d_{Lo} + d_{s1})$ km $\quad$ (1.3a)

For $d > (d_{Lo} + d_{s1})$ km, $\quad d_e = 130 + d - (d_{Lo} + d_{s1})$ km. $\quad$ (1.3b)

In each climatic region the calculated reference value should be adjusted by the amount $V(0.5, d_e)$ to obtain the predicted all-year median value of attenuation.

The curves shown in figure 1.1 represent $V(0.5, d_e)$ for all hours of the day throughout the entire year. For some applications it is important to know something about the diurnal and seasonal changes that

THE ADJUSTMENT FACTOR $V(0.5,\ d_e)$ FOR 8 CLIMATIC REGIONS

$A(0.5) = A_{cr} - V(0.5,\ d_e)$ dB

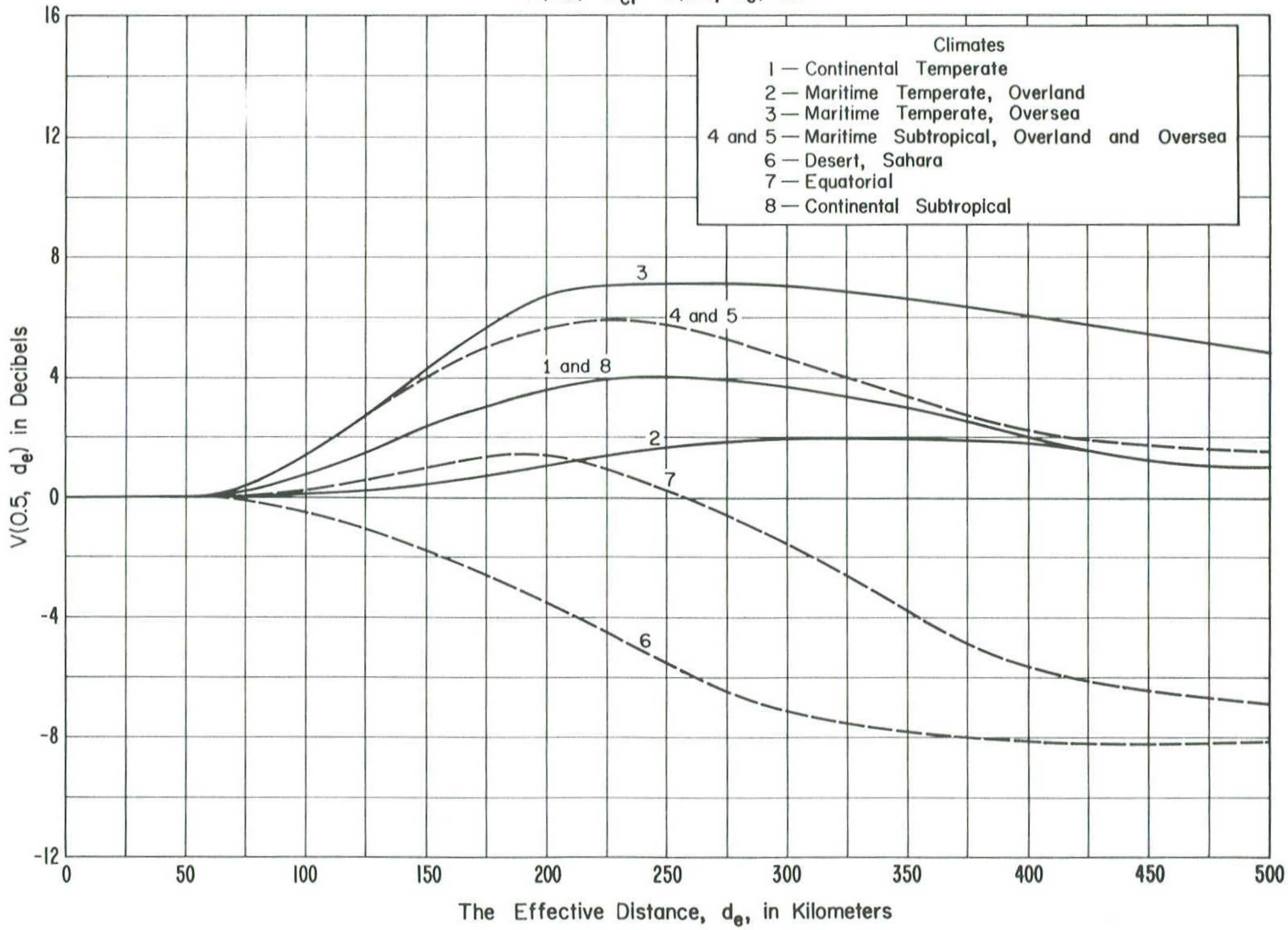


Figure 1.1

may be expected. Such changes have been studied in the continental United States where a large amount of data, recorded for periods of at least a year, is available. The variation of long-term median levels with season usually shows maximum attenuation in midwinter, especially on winter afternoons, and minimum attenuation during the summer months, particularly during the morning hours.

The data were divided into summer and winter periods, May through October, and November through April, and the hours of the day were divided into four groups providing the following eight time blocks:

No.	Months	Hours
1	Nov - Apr	0600 - 1300
2	Nov - Apr	1300 - 1800
3	Nov - Apr	1800 - 2400
4	May - Oct	0600 - 1300
5	May - Oct	1300 - 1800
6	May - Oct	1800 - 2400
7	May - Oct	0000 - 0600
8	Nov - Apr	0000 - 0600

The data for time blocks 1, 2, 3, and 8 were combined to form a winter all-hours group and the data for time blocks 4, 5, 6, and 7 were combined to form a summer all-hours group. The adjustment factor $V(0.5)$ for each of these periods of time is shown in figure 1.2 for the United States, which is typical of a continental temperate climate.

For other climatic regions an indication of the seasonal variation to be expected may be obtained from the annual range of monthly mean N_s shown in figure 1.3. Much of the data in the United States was recorded where the annual range of monthly mean N_s is 40 to 50 N-units. In regions where the annual range is less than 20 N-units, seasonal variations

THE FUNCTION $V(0.5, d_e)$ FOR VARIOUS PERIODS OF TIME IN THE U.S.A.

$A(0.5) = A_{cr} - V(0.5, d_e)$ dB

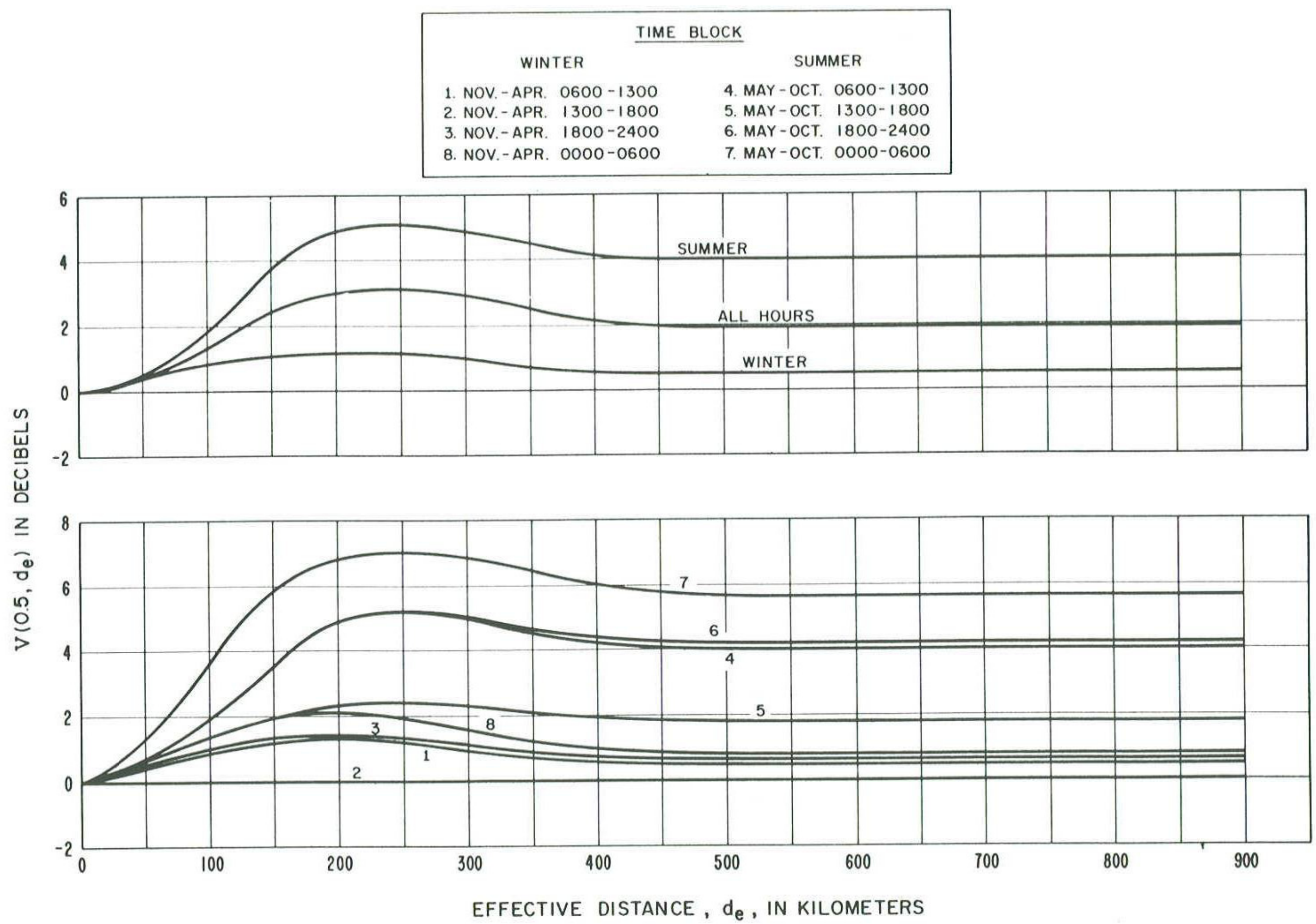


Figure 1.2

ANNUAL RANGE OF MONTHLY MEAN N_s

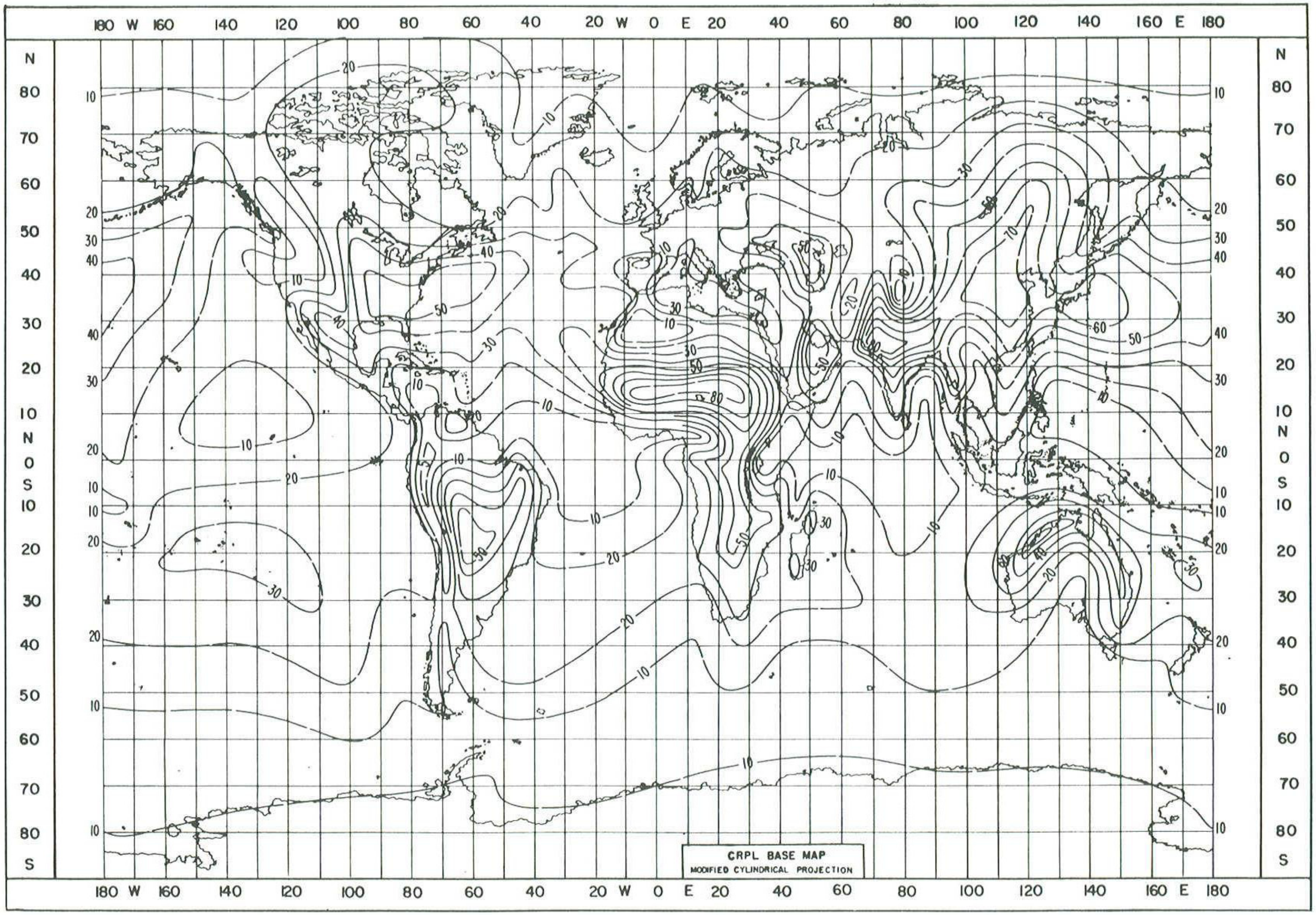


Figure 1.3

are expected to be negligible. One would also expect less diurnal change, for example, in a maritime temperate climate where changes in temperature during the day are less extreme. In climates where the surface refractivity N_s changes considerably throughout the year, the consecutive 4-to 6-month period when the monthly mean value of N_s is lowest is assumed to correspond to "winter", whatever months are involved.

1-1.2 Long-Term Variability About the Median

Long-term variability, identified with the variability of hourly median values of attenuation, usually results from slow changes in average atmospheric refraction, in the degree of atmospheric stratification, or in the intensity of atmospheric turbulence. Estimates of long-term variability to be expected are important to insure adequate service and to avoid possible interference between services operating on the same or adjacent frequencies.

Estimates of variability in time about the long-term median attenuation are based on measurements. Hourly median values of transmission loss recorded for a long period of time over a single path may show wide variations, especially in areas where marked seasonal changes occur in the surface refractivity N_s and in the refractive index gradient.

Figure 1.4 shows the variability expected at 100 MHz in a continental temperate climate for all hours of the year, for the summer hours, and for the winter hours. The curves show the interdecile range of attenuation as a function of the effective distance d_e. They were drawn through medians of a large amount of data recorded in the frequency range 88 to 108 MHz. The curve $Y_o(0.1)$ is the difference between the median attenuation $A(0.5)$ and the attenuation $A(0.1)$ not exceeded 10 percent of the time. Similarly, the curve $Y_o(0.9)$ represents the difference between the median attenuation and the attenuation $A(0.9)$ not exceeded 90 percent of the time:

$$Y_o(0.1) = A(0.5) - A(0.1) \equiv L_b(0.5) - L_b(0.1) \text{ dB} \tag{1.4a}$$

$$Y_o(0.9) = A(0.5) - A(0.9) \equiv L_b(0.5) - L_b(0.9) \text{ dB} \tag{1.4b}$$

The variability in time of attenuation over a given path also depends on frequency-related effects. The frequency factors $g(0.1, f)$ and $g(0.9, f)$ shown in figure 1.5 adjust the predicted variability for 100 MHz, shown in figure 1.4 for use at other frequencies:

$$Y(0.1) = Y_o(0.1)\, g(0.1, f) \text{ dB} \tag{1.5a}$$

$$Y(0.9) = Y_o(0.9)\, g(0.9, f) \text{ dB}. \tag{1.5b}$$

The empirical curves $g(q, f)$ should not be regarded as an estimate of the dependence of long-term variability on frequency; they represent only an average of many effects, some of which are frequency-sensitive. The apparent frequency dependence is a function of the relative dominance of various propagation mechanisms, which in turn depends on climate, time of day, season and the particular types of terrain profiles for which data are available. An allowance for year-to-year variability is included in $g(q, f)$.

The estimates of A_{cr}, $V(0.5)$, $Y(0.1)$ and $Y(0.9)$ may be used to predict an entire cumulative distribution of attenuation relative to free space using the following ratios:

$$Y(0.0001) = 3.33\, Y(0.1) \qquad Y(0.9999) = 2.90\, Y(0.9)$$

$$Y(0.001) = 2.73\, Y(0.1) \qquad Y(0.999) = 2.41\, Y(0.9)$$

$$Y(0.01) = 2.00\, Y(0.1) \qquad Y(0.99) = 1.82\, Y(0.9)$$

LONG-TERM POWER-FADING FUNCTION $Y_0(q,d_e)$
CONTINENTAL TEMPERATE CLIMATE

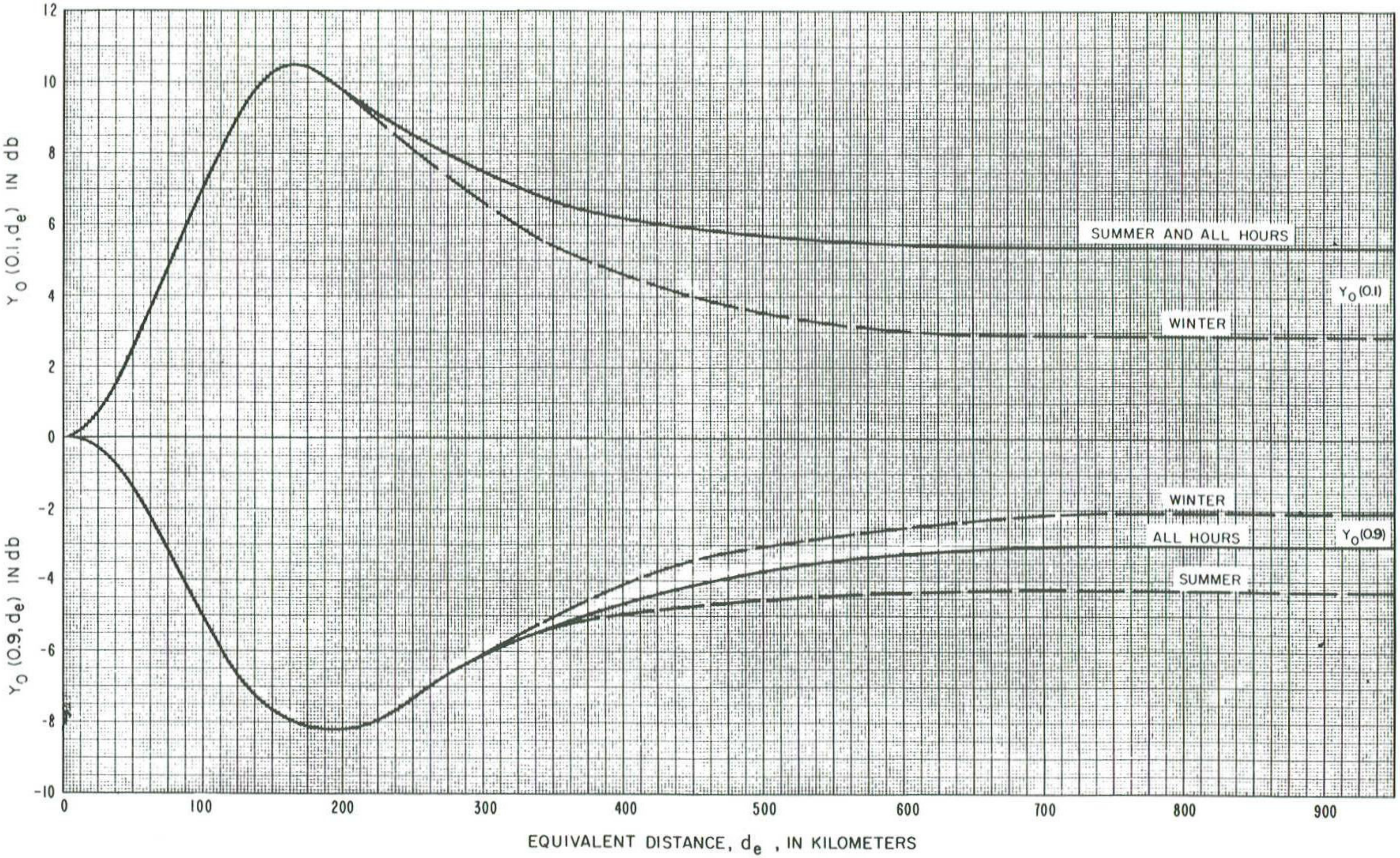
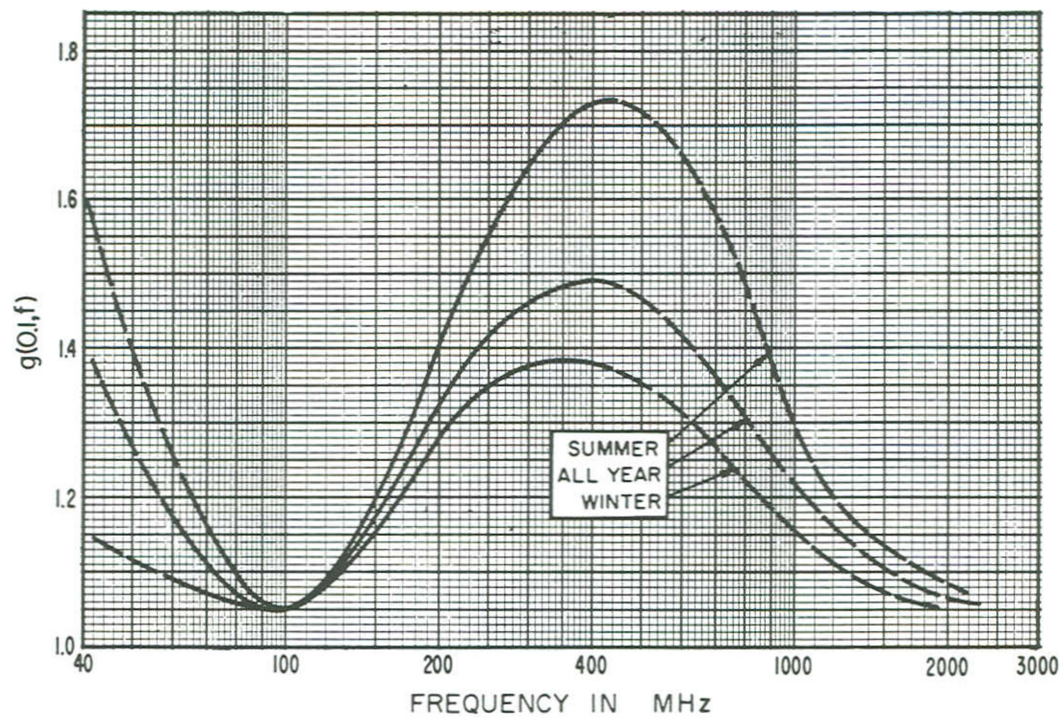


Figure 1.4

THE FREQUENCY FACTOR g(q, f)
BASED ON U.S. OVERLAND DATA



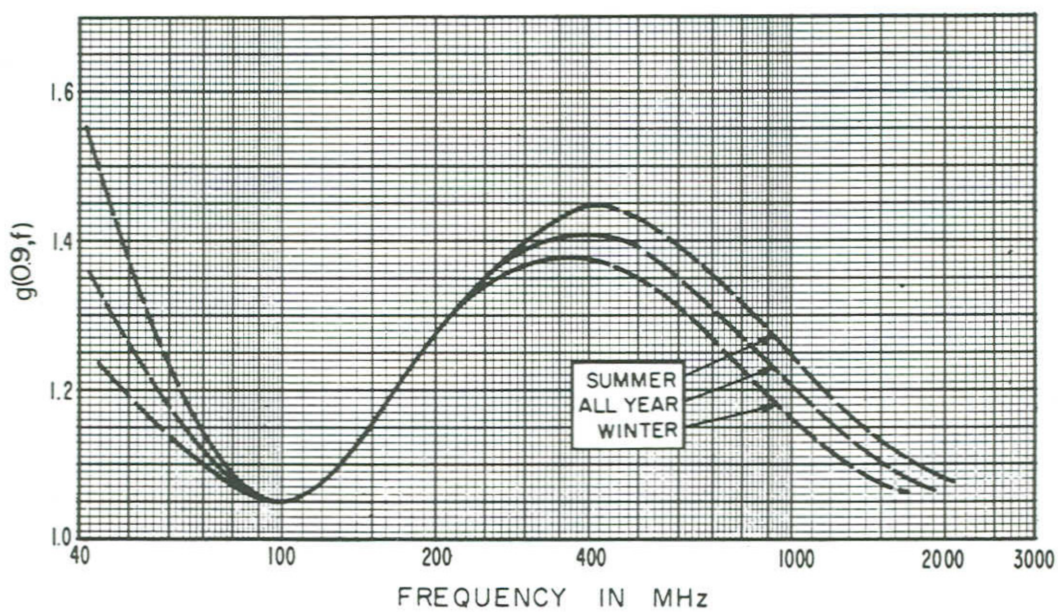


Figure 1.5

Figure 1.6 shows such a predicted distribution compared with values measured over a path for more than 2 years. The figure shows the bivariate distribution that is typical of a continental temperate climate.

The preceding discussion and figures 1.2, 1.4, and 1.5 are for a continental temperate climate and are based largely on data from measurements made in the United States and in West Germany. Data from other geographical regions were used to develop curves for other climates, notably data from the British Isles and the west coastal areas of Europe that characterize the maritime temperate overland and maritime temperate oversea curves. The curves presented by Rice et al.(1967) for other climatic regions are based on relatively few measurements.

1-1.3 Computer Method for Estimating Long-Term Variability

Long-term variability about the median attenuation may be estimated in terms of a standard deviation, σ_{Ta}, and a standard normal deviate, $z_o(q)$. The symbol q, representing any fraction between 0 and 1, and the standard normal deviate $z_o(q)$ may be expressed in terms of the error function, erf x, and its inverse, $\text{erf}^{-1} x$.

$$q = 0.5 + 0.5 \, \text{erf}(z_o/\sqrt{2}) \tag{1.6a}$$

$$z_o(q) = \sqrt{2} \, \text{erf}^{-1} (2q-1). \tag{1.6b}$$

Then the long-term variability about the median exceeded at least a fraction q_T of the time may be expressed as

$$Y(q_T) = -\sigma_{Ta} \, z_o(q_T) \text{ dB}, \tag{1.7}$$

where q_T is any desired fraction of time and $Y(q_T)$ is the difference between the median attenuation $A(0.5)$ and the attenuation not exceeded a fraction q_T of the time.

COMPARISON OF MEASURED AND PREDICTED ATTENUATION, OVER A PATH FROM CHICAGO TO URBANA, ILLINOIS

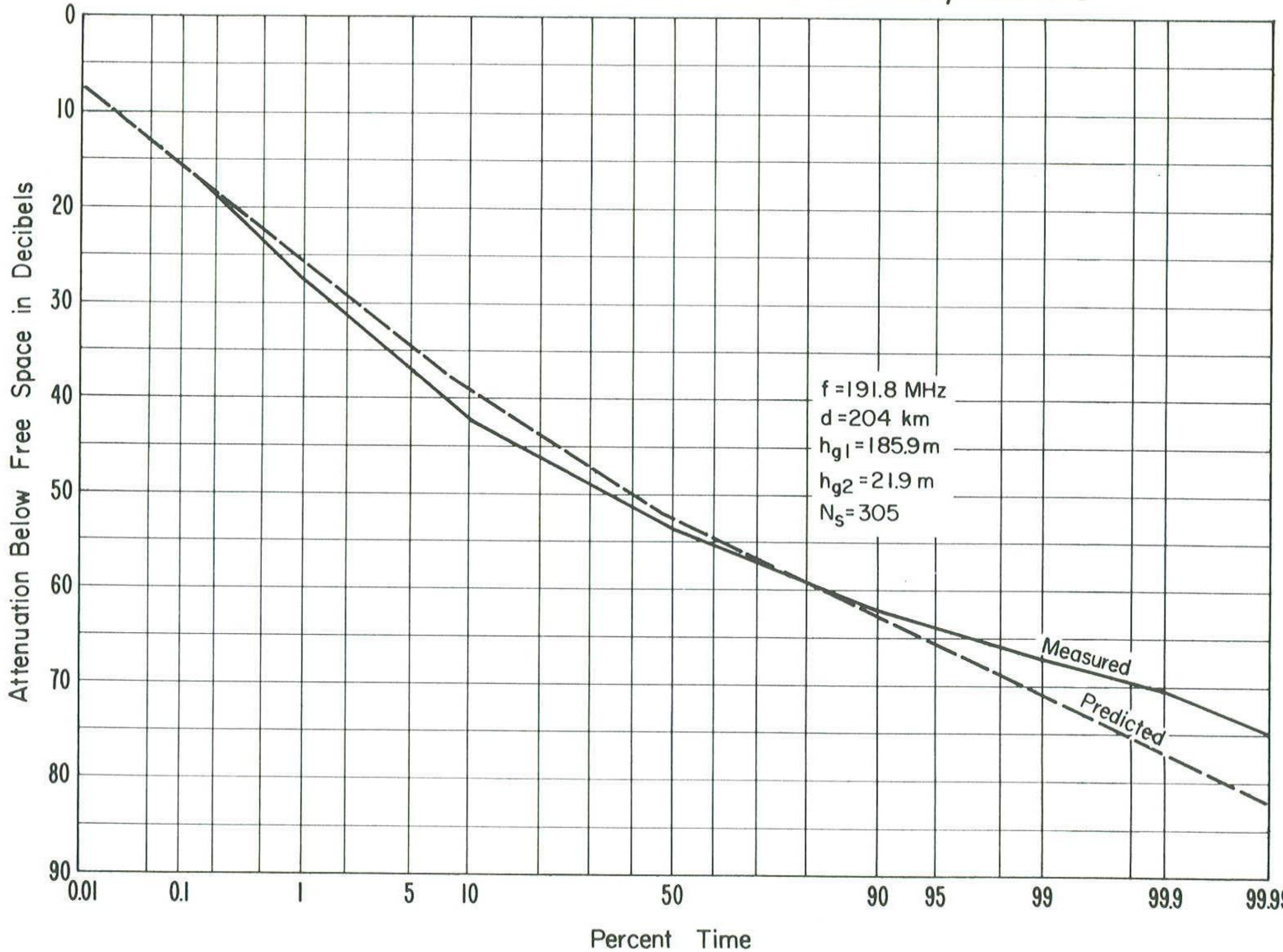


Figure 1.6

For a continental temperate climate, $Y(0.1)$ is not equal to $Y(0.9)$. The cumulative distribution may be considered as consisting of two parts, represented by standard deviations $\sigma_{Ta}(0.1)$ and $\sigma_{Ta}(0.9)$, where

$$Y(0.1) = 1.282\,\sigma_{Ta}(0.1), \text{ and} \tag{1.8a}$$

$$Y(0.9) = -1.282\,\sigma_{Ta}(0.9). \tag{1.8b}$$

Define $x = d_e/100$.

For $d_e \le 200$:

$$\sigma_{Ta}(0.1) = 8\,x^2 g(0.1, f)\,\exp(-0.36\,x^2). \tag{1.9a}$$

For $d_e > 200$:

$$\sigma_{Ta}(0.1) = g(0.1, f)\left[4.2 + 16.5\,\exp(-0.77\,x)\right]. \tag{1.9b}$$

For $d_e \le 250$:

$$\sigma_{Ta}(0.9) = 4.6\,x^2\,g(0.9, f)\,\exp(-0.26\,x^2). \tag{1.10a}$$

For $d_e > 250$:

$$\sigma_{Ta}(0.9) = g(0.9, f)\left[2.3 + 15\,\exp(-0.6\,x)\right]. \tag{1.10b}$$

For $60 \le f \le 1600$ MHz:

$$g(0.1, f) = 0.21\,\sin\left[5.22\,\log_{10}(f/200)\right] + 1.28, \tag{1.11a}$$