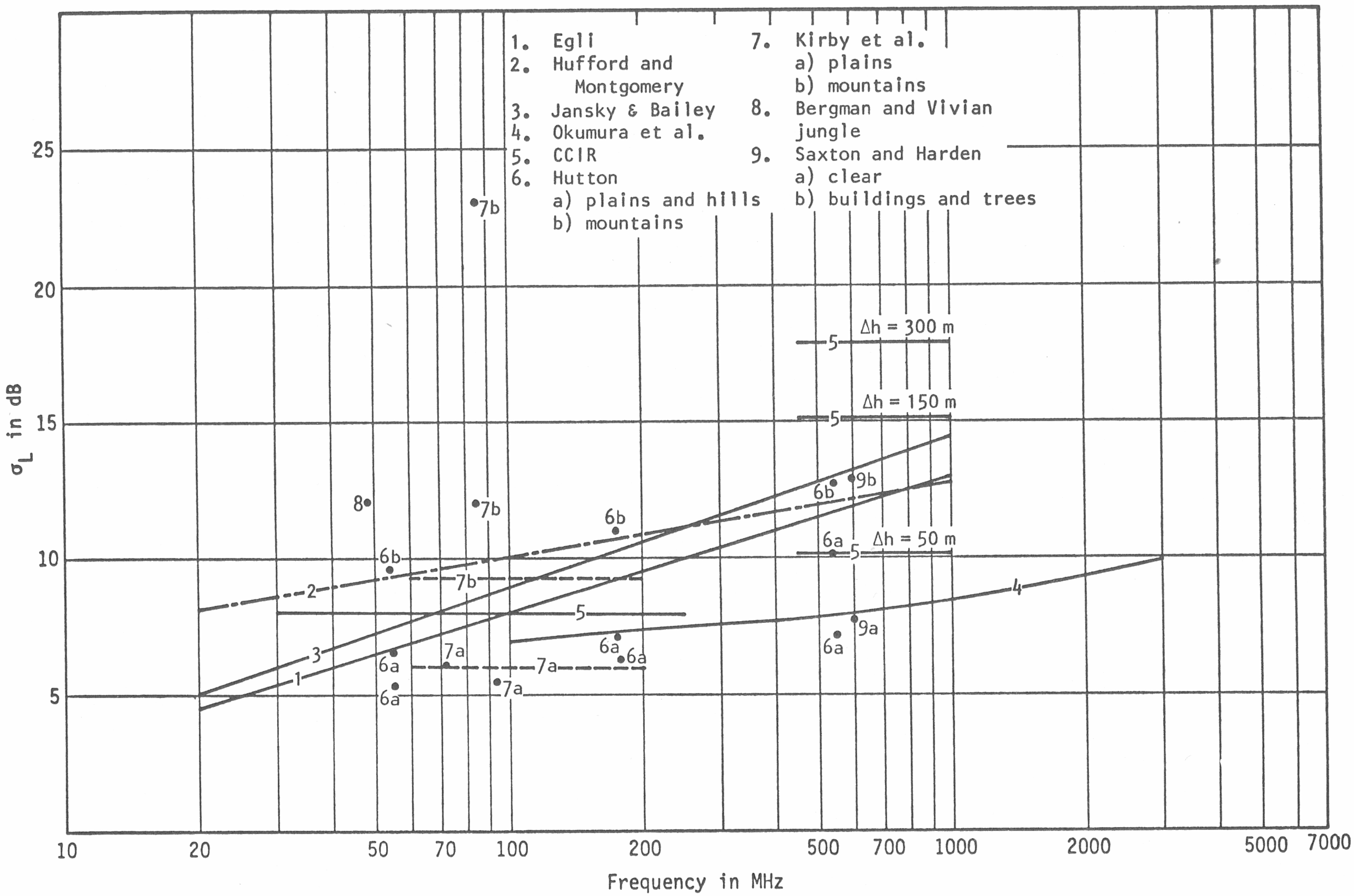

Figure 2. Standard deviation of location variability, σ_L, as a function of frequency in non-urban areas. Here Δh is the interdecile range of terrain elevations in the range 10 to 50 km from the transmitter.

variability one should expect in any given area, for any specific frequency. Most of these data were obtained in broadcasting or mobile situations with the transmitting antenna considerably elevated and the receiving antennas from 3 to 10 m above ground. In the present study we shall consider systems with rather low antennas in non-urban areas, where differences in terrain type as well as frequency are important.

Several sets of measurements are available at frequencies from 20 to 10,000 MHz in areas that range from plains to rugged mountains. These measurements were carried out by OT/ITS personnel under the supervision of Mr. A. P. Barsis. They include data obtained in the Colorado plains and mountains, and in hilly terrain in Ohio at VHF; data at UHF and SHF with several receiver heights in four quite different types of terrain in Colorado and in Virginia; and data from a series of measurements with very low antennas in Wyoming, Idaho, and Washington. These data are spot measurements, rather than the result of long-term observations, and were obtained over paths ranging from 0.5 to 120 km in length. They are described in a series of reports by Barsis et al. (1964, 1969), Barsis and Miles (1965), Hause et al. (1969), Johnson et al. (1967), and McQuate et al. (1968, 1971). A report by Longley and Reasoner (1970) compares these measurements with predicted values. A preliminary examination of the data indicates that location variability increases with increasing frequency and terrain irregularity. No clear-cut dependence on path length or antenna elevation was observed.

A suitable reference level is required in order to describe variability. For the VHF data the measurements were made at locations chosen at random on circular arcs around the transmitter location. For these data the distribution of values at each distance about their own mean was a suitable choice. Another technique that could be used would be to group the values by distance ranges and determine the mean and standard deviation of transmission loss within each range. One difficulty in this approach is that many of the paths are quite short and transmission loss increases rapidly with distance for small distances. Another difficulty is that some series of measurements contain only a few values so that it would be desirable to treat the entire set as a single group, provided that a suitable reference could be found.

Some workers have chosen calculated free space or "smooth-earth" values as a reference. However, we have found that location variability can be estimated readily in terms of variability of measured values about the median level predicted at each distance using the methods developed by Longley and Rice (1968). Using predicted values as a reference allows us to consider all of the data in a set regardless of differences in path length. We, therefore, consider location variability in terms of the differences between predicted and measured values. Distributions of these differences, $\Delta L =$ (L predicted -L observed), for all groups of data show that ΔL is normally distributed and can be adequately represented by the mean, or median, and standard deviation. The mean value of ΔL represents the agreement between predicted medians and the medians of measured values, while the standard deviation, σ_L, is the path-to-path or location variability.

The efficacy of this approach was tested by comparison with the results of a statistical study by Hufford and Montgomery (1966) of VHF data, taken with both transmitting and receiving antennas near the ground. This large body of measurements was made at frequencies of 20, 50, and 100 MHz over three very different types of terrain: in the plains and mountains of Colorado, and the wooded hills near Cleveland, Ohio. The receiver sites were selected randomly at distances of 5, 10, 20, 30, 50, and 80 km from the transmitter site (Barsis et al., 1964). The data from each area were grouped for each frequency, polarization, antenna-height combination, and distance. The measured values in each group were found to be normally distributed about their mean, with no consistent change in standard deviation with increasing distance. The authors then assumed that σ_L is independent of distance, and averaged the variances over all distances to obtain an estimate of σ_L for each group of data.

For the same series of measurements we obtained distributions of the differences, ΔL, between predicted and measured values of transmission loss. The standard deviations of these differences are listed in table 1, with corresponding values computed by Hufford and Montgomery. The estimates of σ_L for data at all distances agree quite well with the values which were obtained by averaging the variances calculated at each distance. The table also shows the maximum and minimum values calculated at individual distances (excluding the 5 km value in the Colorado mountains where the sample consisted of only

Table 1. Location Variability, VHF Data

Area	No of Samples	Freq MHz	Antenna Hts, m h_1	h_2	Polari- zation	Range of $\sigma_L(1)$ dB	Mean of $\sigma_L(1)$ dB	σ_L dB	Δh,m
Colorado Plains	172	101.5	4	3	V	6.8-10.9	8.3	8.2	90
				6		5.2-11.1	8.6	9.6	
				9		5.6-10.2	8.5	9.4	
				3	H	7.3-11.6	8.6	8.5	
				6		5.0-12.4	9.0	9.2	
				9		4.9-13.3	9.5	9.2	
	120	49.7		0.6	V	6.1- 8.7	7.1	8.2	
				1.7		6.0- 8.3	6.7	8.1	
		20.1	3.3	1.3		3.7- 7.6	5.4	6.1	
Colorado Mtns	48	101.5	4	3	V	6.7-12.4	9.9	10.5	650
				6		8.7-13.2	9.8	11.7	
				9		8.9-11.4	10.1	12.2	
				3	H	8.8-16.5	12.8	15.5	
				6		9.9-23.7	16.2	16.5	
				9		10.4-19.8	14.6	16.9	
		49.7		0.6	V	5.8-11.0	9.5	11.4	
				1.7		4.7-15.2	9.6	10.0	
		20.1	3.3	1.3		7.7-16.8	10.0	11.6	
Ohio Hills	255	101.8	4	3	V	10.9-12.1	11.5	12.4	90
				6		9.5- 9.7	9.4	10.1	
				9		8.1-10.4	9.0	10.2	
				3	H	8.3-10.5	9.3	10.6	
				6		7.9- 9.5	9.4	9.7	
				9		7.6-10.6	9.5	9.8	
		49.7	4.2	1	V	7.0- 8.6	10.2	8.0	
				3		7.1- 7.7	8.8	7.7	
		20.0	3.7	3		6.3- 9.4	7.8	6.8	

Range of $\sigma_L(1)$ - Minimum and maximum values of $\sigma_L(1)$ calculated at each distance from the transmitter.

Mean of $\sigma_L(1)$ - Estimate of σ_L, variances are averaged over distance, Hufford and Montgomery (1966).

σ_L - Standard deviation of ΔL where ΔL = (L predicted -L observed).

Δh - is the interdecile range of terrain elevations in m, as defined by Longley and Rice (1968).

two values). Part of this range in estimates of σ_L undoubtedly results from small samples at some distances, especially in the mountain data. The estimates using predicted values as a reference tend to be somewhat larger than those obtained by summing the variances at each distance, but the differences are small compared to the range in values of σ_L calculated at each distance.

These VHF data show an increase in variability with increasing frequency and terrain irregularity, as previously noted. They show little differences between the variability of vertically and horizontally polarized signals in the plains and hills but somewhat more variability with horizontal polarization in the mountains. Increasing the receiving antenna height from 3 to 9 m shows no consistent change in the values of σ_L.

Estimates of location variability were made for several sets of data that represent broadcast and mobile conditions. In general one or more receivers were set up at what appeared to be average sites and mobile transmitting units went to various locations that had been selected from maps. These were chosen along accessible roads without regard to local terrain, and represent randomly selected sites. The measurements include the VHF data listed in table 1 and data from several areas at higher frequencies as shown in table 2.

The large body of measurements in Virginia was made with the receiving antenna either clear of immediate obstructions (open sites) or placed among trees (concealed sites). For the Colorado measurements a receiver site was chosen for each set and the transmitters were mobile. Receiver site R1 was located on a hill near Boulder, R2 in the high mountains west of Boulder, R3 on the eastern edge of a high mesa near Golden, and R4 in a grove of deciduous trees in the plains near Longmont. The measurements in Wyoming, Idaho, and Washington at 230 and 416 MHz were made with very low antennas, from 0.7 to 3 m above ground at both transmitting and receiving terminals. In this series no attempt was made to choose sites with clear foregrounds, and most of the paths were entirely independent of the others, having few common terminals.

These measurements, together with those at VHF in table 1, were all made with low antennas, with heights ranging from 0.3 to 20 m. (The Colorado data at R3 were taken at the edge of a high mesa, so the effective receiver antenna height is large.) They cover a wide range of frequencies, distances, and terrain types, and include paths in open areas and those partially obstructed by evergreen and deciduous trees. These data were used to study

Table 2. List of Data at UHF/SHF

Area	Δh,m	Antenna hts h1,m	Antenna hts h2,m	Range of Freq,MHz	Range of Dist,km	No of Paths
Virginia						
Open	77	10-15	2-15	75-9000	0.5-120	256
Concealed			10-15		20-120	225
Colorado						
R1	90	6.6,7.3	1,3,7,10	230-9190	0.5-120	47
R2	510					41
R3	146					65
R4	50					35
Wyoming	120	0.7-3	0.7-3	230,416	2-45	46
Idaho	63				10-45	30
Washington,						
Ritzville	70				10-60	15
Other	260				2-60	39

(Δh as defined by Longley and Rice (1968) is expressed in meters and the range of frequencies in megahertz.)

the dependence of location variability on frequency, terrain type, vegetation, and other factors.

Values of the standard deviation σ_L of path-to-path variability for each group of data are plotted versus frequency in figure 3. A wide range of values at each frequency is immediately apparent. On closer examination we see that the largest values of σ_L occur in highly irregular terrain, in the Colorado mountains at all frequencies, in the irregular terrain in Wyoming and Washington, and at the higher frequencies at the concealed sites in Virginia. This indicates that terrain irregularity and the presence of trees or other objects near the receiver have a strong effect on location variability.

Considering the effects of terrain irregularity we note that the variability is greatest in mountainous terrain and increases with increasing frequency. This suggests the use of a parameter that combines the terrain irregularity factor, Δh, and the frequency or wavelength of the signal, and that increases as Δh and/or f increase. The unitless term ($\Delta h/\lambda$) meets these requirements. Values of σ_L for more than 135 groups of data were, therefore, plotted versus the parameter $\Delta h/\lambda$, as shown in figure 4. The range of values