

# LOCATION VARIABILITY OF TRANSMISSION LOSS -- LAND MOBILE AND BROADCAST SYSTEMS

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# LOCATION VARIABILITY OF TRANSMISSION LOSS

## LAND MOBILE AND BROADCAST SYSTEMS

Anita G. Longley\*

This report summarizes the results of a number of studies of path-to-path, or location, variability of transmission loss at 20 MHz to 10 GHz. The studies show that such variability appears to be normally distributed and can, therefore, be represented by a standard deviation. Location variability increases with increased frequency and terrain irregularity, the standard deviation increasing from about 5 to 25 dB. For non-urban areas an expression is given which defines location variability in terms of radio frequency and terrain irregularity. The effects of tall buildings in highly built-up urban areas, and of trees are discussed.

Key words: Broadcast systems; irregular terrain; location variability; mobile systems; radio transmission loss; urban communications; vegetation.

### 1. INTRODUCTION

In a broadcast or mobile system, at frequencies above 20 MHz, a great deal of variability in signal level among paths of the same length is to be expected. Such path-to-path or location variability must be taken into account in estimating the coverage of a broadcasting station, or the useful range from a base station to mobile units.

Estimates of location variability are empirical, derived from measurement programs. As a rule radio signals are transmitted from a broadcast or base station with elevated antennas to rather low and randomly located receivers. The receiving antennas are usually from 3 to 10 m above ground, but may be somewhat lower. The measurement programs show that location variability appears to be normally distributed with a standard deviation that ranges from about 5 to 25 dB depending on radio frequency, type of terrain, and whether the path terminals are in open or cluttered surroundings. No clear-cut dependence on antenna heights has been noted.

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## 2. PREVIOUS WORK

A number of studies of location variability have been made in the frequency range from 20 to 3000 MHz in both urban and rural situations, and over smooth and irregular terrain. The results of several programs are summarized here.

Some early measurements were made by R. S. Kirby and his associates. Kirby and Capps (1956) reported on mobile measurements at frequencies of 72 and 94 MHz in the Washington, D.C. and Baltimore areas. They noted little variability for paths which were largely over water, but 10 to 90% ranges of 11 to 18 and 13 to 15 dB at 72 and 94 MHz, respectively, in urban and wooded areas and in farmlands. If we assume that the measured values are normally distributed this would correspond to standard deviations  $\sigma_L \approx 6$  and 5.5 dB at these frequencies. Kirby et al. (1956) reported mobile measurements in Colorado at frequencies of 60, 95.7, and 192 MHz on four east-west routes 32, 56, 74, and 99 km north of the transmitters in Denver. In all cases higher values of location variability were associated with the rougher terrain, with median values  $\sigma_L \approx 6.1$  and 9.1 dB in the plains and foothills, respectively. Later measurements at 88 MHz along circular routes around Denver, reported by Kirby (1957), showed that values of variability increased with increasing terrain irregularity. He reported  $\sigma_L \approx 6$ , 12, and 23 dB in average, hilly, and mountainous terrain, respectively.

A large measurement program was conducted mainly in the eastern part of the U.S. by the Television Allocation Study Organization (TASO). Head and Prestholdt (1960) reported that these measurements showed a much wider range of field strength values at UHF than at VHF, and much more variability in rugged than in smooth terrain.

Egli (1957), working with data from mobile units in irregular terrain, found that the signal levels for different paths of the same length appeared to be normally distributed with standard deviations of 8.3 and 11.6 dB at frequencies of 127.5 and 510 MHz, respectively. He suggested that the standard deviation,  $\sigma_L$ , be expressed as a function of radio frequency,

$$\sigma_L = 5 \log f - 2 \text{ dB}, \quad (1)$$

where  $f$  is the frequency in MHz.

From a statistical study of data recorded in the lower VHF range, Hufford and Montgomery (1966) reached a similar conclusion, and suggested that location variability be represented as

$$\sigma_L = 3 \log f + 3.6 \text{ dB.} \quad (2)$$

They noted somewhat greater variability in mountainous areas than in plains, but did not suggest a specific allowance for terrain irregularity. From a study of the same data, Longley and Rice (1968) noted a consistent dependence on frequency and terrain irregularity. They derived an expression to show that  $\sigma_L$  increases as the ratio of terrain irregularity to wavelength increases.

From a study of measurements at frequencies from 25 to 400 MHz in tropical jungles, Jansky and Bailey (1965) suggested that location variability be represented as a function of frequency with a standard deviation

$$\sigma_L = 5.7 \log f - 2.6 \text{ dB.} \quad (3)$$

Bergman and Vivian (1970), reporting a series of long-range measurements in heavy foliage in the mountainous terrain of Panama at 49.4 MHz over distances up to 40 km, found much greater path-to-path variability, with  $\sigma_L \approx 12$  dB.

Saxton and Harden (1954), in a series of measurements at 600 MHz over paths up to 8 km in length, observed 10 to 90% ranges in signal level of 19 to 34 dB, or  $\sigma_L \approx 7.5$  to 13.5 dB. They observed the effects of trees and buildings near the receiving antenna with local variations of 2 to 4 dB at open sites and as much as 20 to 25 dB in a hollow with many trees and buildings.

The International Radio Consultative Committee (CCIR, 1970a) reports a variation factor,  $V$ , for towns in the United Kingdom, (where  $V$  is the 50 to 90% range in field strength). For 121 towns, at frequencies from 700 to 1000 MHz, the median  $V = 9.8$  dB, and for 40 towns, at 250 MHz, the median  $V = 7.7$  dB. These location variabilities correspond to values of  $\sigma_L \approx 7.9$  and 6.3 dB, respectively. For non-urban areas, the CCIR (1970b) suggests that for irregular terrain the location variability at frequencies from 30 to 250 MHz be represented by  $\sigma_L = 8$  dB, but that for frequencies from 450 to 1000 MHz the location variability is also a function of terrain irregularity, with

$\sigma_L = 9.5, 15, \text{ and } 18 \text{ dB}$  for average, hilly, and mountainous terrain.

From a statistical study of a large number of measurements in Tokyo and its environs, Okumura et al. (1968) proposed curves of  $\sigma_L$  as a function of frequency in urban and suburban areas for frequencies from 100 to 3000 MHz. The urban region in the heart of Tokyo is in flat terrain, while the suburban region is hilly. Their curves show greater variability in the hilly suburbs than in the urban area, but it should be noted that until recently the heights of buildings in Japan were limited by law to about 31 m. The curves show values of  $\sigma_L = 5.2$  and  $6.7 \text{ dB}$  at 100 MHz, increasing to  $\sigma_L = 8$  and  $10 \text{ dB}$  at 3000 MHz for urban and suburban areas, respectively.

In contrast to the studies in Japan, Waldo (1963) observed large location variability in the highly built-up areas of New York City, where the terrain itself is quite flat. He reports location variability with  $\sigma_L = 16, 17, \text{ and } 18 \text{ dB}$  at frequencies of 55, 175, and 573 MHz measured at roof tops. Neham (1974) suggests using values of  $\sigma_L = 9, 11.6, \text{ and } 14 \text{ dB}$  at frequencies of 50, 150, and 450 MHz, respectively, to allow for location variability in an urban area.

The large measurement program conducted by the Federal Communications Commission, and reported by Waldo (1963), also included measurements along several radials to a distance of 128 km. The data from these measurements are reported by Hutton (1963). Signals were transmitted from the top of the Empire State Building in New York City at frequencies of 55, 175, and 573 MHz. The data clearly showed greater variability at the highest frequency, and also more path-to-path variability along radials over mountains than along those over relatively smooth terrain. For paths over smooth terrain values of  $\sigma_L$  are approximately 5, 6, and 7 dB at frequencies of 55, 175, and 573 MHz, respectively. The corresponding values at these frequencies over hilly terrain are approximately  $\sigma_L \approx 6.5, 7, \text{ and } 10.5 \text{ dB}$ , increasing to 10, 11, and 13 dB over mountainous terrain. Values of field strength measured around a circle with a 37 km radius, where terrain ranged from smooth to mountainous, showed even more variability at the highest frequency, with  $\sigma_L \approx 16 \text{ dB}$ .

In a study in Philadelphia at 836 MHz, Black and Reudink (1972) noted that near the transmitter the location variability of  $\sigma_L \approx 9 \text{ dB}$  was greater than in a region farther away where the buildings were more uniform, with

$\sigma_L \approx 5.5$  dB. Reudink and Wazowicz (1973) in a series of measurements from a base station in Holmdel, New Jersey, at 836 MHz and 11.2 GHz noted increased location variability with increased frequency, and also with increased distance from the base station. At 836 MHz they estimated values of  $\sigma_L = 7$  to 8, 10 to 11, and 15 dB for distance ranges of 1.5 to 2.5, 2.5 to 3.5, and 3.5 to 5.5 km, respectively. Similarly at 11.2 GHz values of  $\sigma_L = 8$  to 9, 12 to 14, and 18 to 20 dB were calculated for the same distance ranges. They chose a suburban rather than a truly urban area in order to avoid shadowing by very tall buildings, and the frequently observed channeling of radio signals along streets, with improved reception at street intersections.

These estimates of location variability are plotted in figures 1 and 2. Figure 1 shows the wide spread in estimates of  $\sigma_L$  for urban and suburban areas. The lower values are typical of conditions in Tokyo, Warsaw (CCIR 1969), and medium-sized cities and towns in the United Kingdom and other countries. The higher estimates are for the canyon-like streets of Manhattan and other heavily built-up areas with many trees. For urban and suburban areas we see that although location variability increases with frequency it is also highly dependent on the type and density of surface features such as buildings and trees.

The location variability in non-urban areas, plotted in figure 2, also shows a definite increase with increasing frequency, and an increase with increasing terrain irregularity. Some man-made and natural objects were present in these areas, but their effects were not sufficient to obscure the effects of frequency and terrain irregularity.

Although one might expect changes in antenna height to affect the amount of location variability, the only observed changes could be attributed to clutter. Signals received by a mobil unit with a 1.5 to 3 m antenna height are somewhat more affected by clutter than those received at roof-top levels. Except in heavily built-up areas no consistent change with path length was observed.

### 3. LOCATION VARIABILITY IN NON-URBAN AREAS

It is obvious from an examination of the values plotted in figures 1 and 2 that a good deal of uncertainty exists as to how much path-to-path



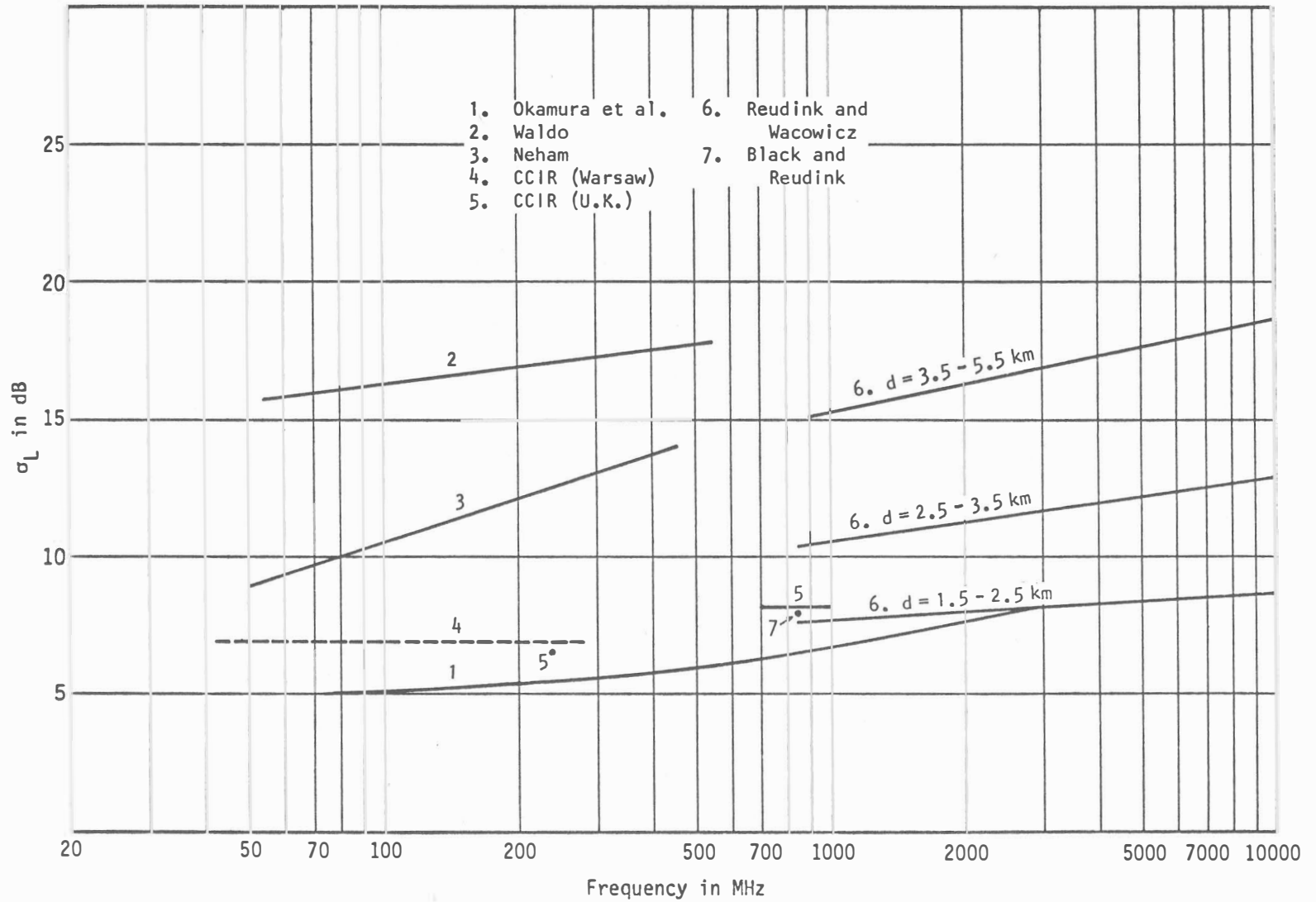


Figure 1. Standard deviation of location variability,  $\sigma_L$ , as a function of frequency in urban areas.

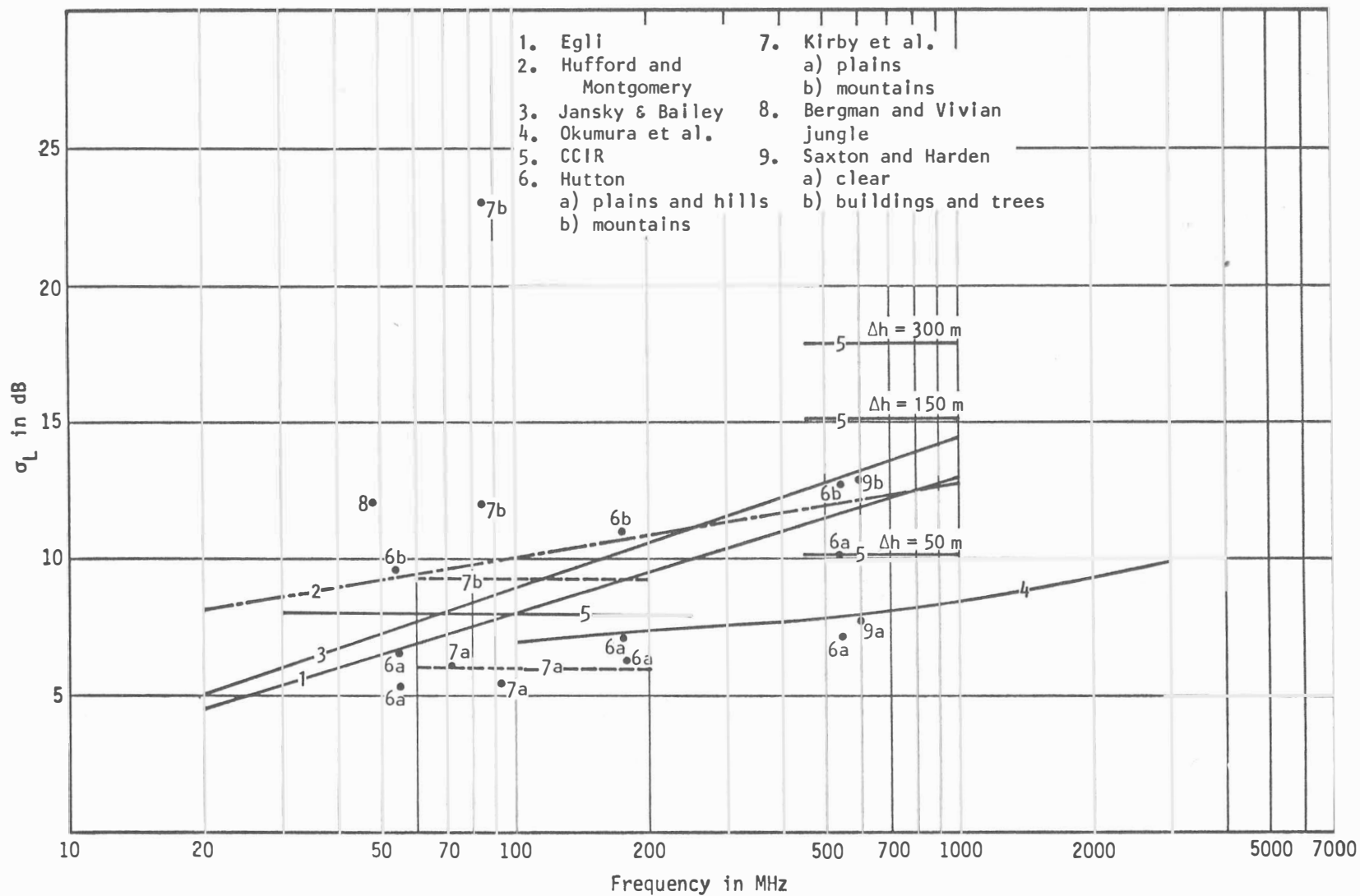


Figure 2. Standard deviation of location variability,  $\sigma_L$ , as a function of frequency in non-urban areas. Here  $\Delta h$  is the interdecile range of terrain elevations in the range 10 to 50 km from the transmitter.

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,  $\Delta L = (L \text{ predicted} - L \text{ observed})$ , for all groups of data show that  $\Delta L$  is normally distributed and can be adequately represented by the mean, or median, and standard deviation. The mean value of  $\Delta L$  represents the agreement between predicted medians and the medians of measured values, while the standard deviation,  $\sigma_L$ , 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  $\sigma_L$  is independent of distance, and averaged the variances over all distances to obtain an estimate of  $\sigma_L$  for each group of data.

For the same series of measurements we obtained distributions of the differences,  $\Delta L$ , 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  $\sigma_L$  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		Polarization	Range of $\sigma_L$ (l) dB	Mean of $\sigma_L$ (l) dB	$\sigma_L$ dB	$\Delta h, m$	
			$h_1$	$h_2$						
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		
	120	49.7	20.1	3.3	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
					0.6		6.1- 8.7	7.1		8.2
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		
	49.7	20.1	3.3	1.3	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
					0.6		5.8-11.0	9.5		11.4
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		
	49.7	20.0	3.7	3	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
					1		7.0- 8.6	10.2		8.0
20.0	3.7	3	3	V	7.1- 7.7	8.8	7.7			
					6.3- 9.4	7.8	6.8			

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

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

$\sigma_L$  - Standard deviation of  $\Delta L$  where  $\Delta L = (L \text{ predicted} - L \text{ observed})$ .

$\Delta h$  - 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  $\sigma_L$  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  $\sigma_L$  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  $\sigma_L$ .

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	$\Delta h, m$	Antenna h1, m	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

( $\Delta h$  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  $\sigma_L$  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  $\sigma_L$  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,  $\Delta h$ , and the frequency or wavelength of the signal, and that increases as  $\Delta h$  and/or  $f$  increase. The unitless term  $(\Delta h/\lambda)$  meets these requirements. Values of  $\sigma_L$  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

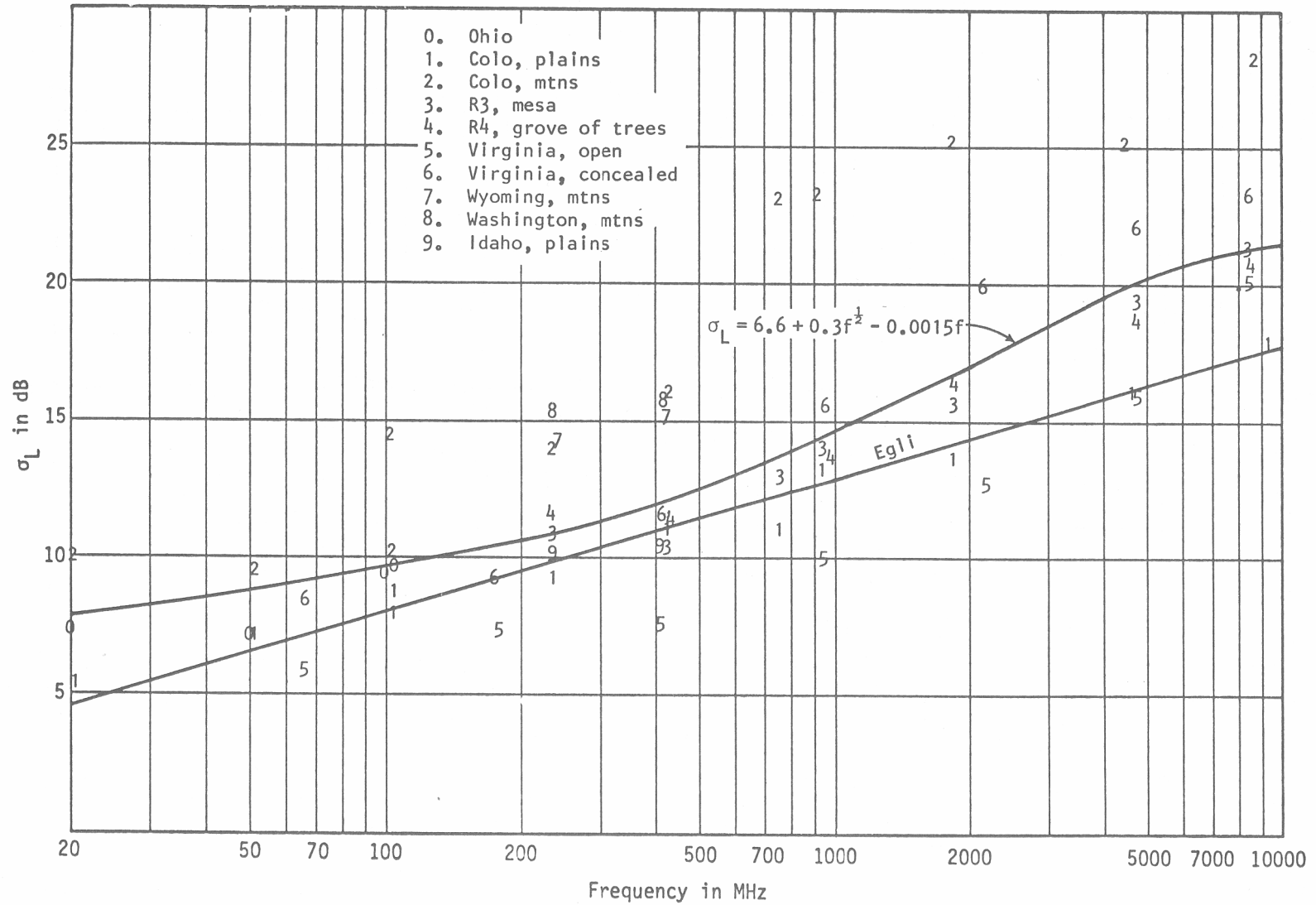


Figure 3. Standard deviation of location variability,  $\sigma_L$ , measured values vs frequency.



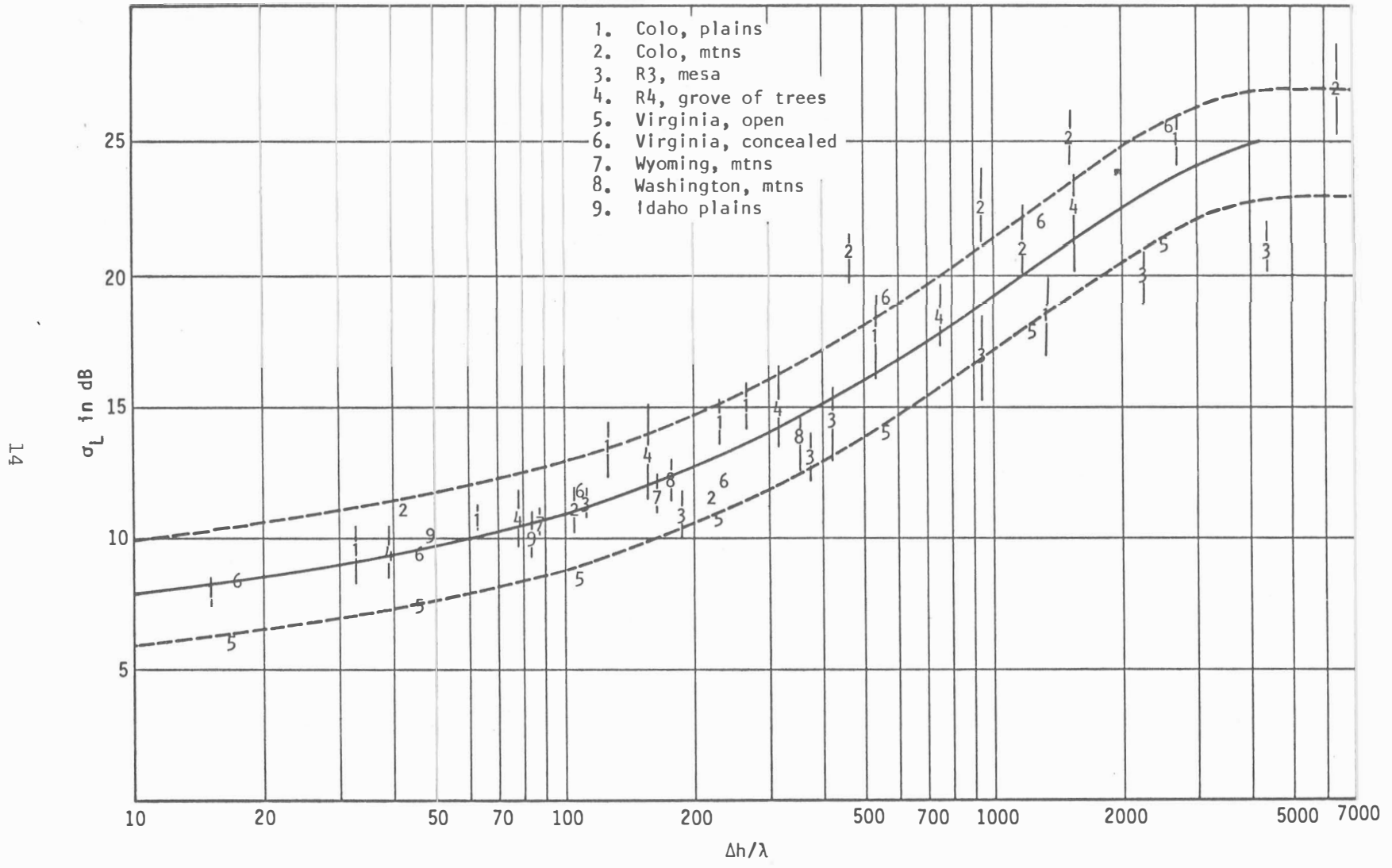


Figure 4. Standard deviation of location variability,  $\sigma_L$ , measured values as a function of the parameter  $\Delta h/\lambda$ .

in each set of data represents different antenna height combinations. Receiver heights of 1, 3, 7, and 10 m were used for the R1 to R4 data. It is readily seen that there is less spread to the data than in the previous plot, and that  $\sigma_L$  increases gradually with increasing values of  $\Delta h/\lambda$ .

This relationship could be approximated quite simply in terms of three straight lines:

$$\sigma_L = 5 + 3 \log (\Delta h/\lambda) \text{ dB, for } 10 \leq \Delta h/\lambda \leq 100 \quad (4a)$$

$$\sigma_L = -6 + 8.7 \log (\Delta h/\lambda) \text{ dB, for } 100 < \Delta h/\lambda \leq 4000 \quad (4b)$$

$$\sigma_L = 25 \text{ dB, for } \Delta h/\lambda > 4000. \quad (4c)$$

A somewhat better fit to the data is obtained using the curve shown on figure 4, which is expressed as

$$\sigma_L = 6 + 0.55 (\Delta h/\lambda)^{\frac{1}{2}} - 0.004 (\Delta h/\lambda) \text{ dB, for } \Delta h/\lambda < 4700 \quad (5a)$$

$$\sigma_L = 24.9 \text{ dB, for } \Delta h/\lambda > 4700. \quad (5b)$$

For convenience in using these estimates they are shown in figure 5 as a series of curves of  $\sigma_L$  versus frequency for various values of  $\Delta h$ . Except for the R2 data in the Colorado mountains 90% of all values lie within 2 dB of this calculated curve. The mountain path data at 20, 50, and 100 MHz fall within 2 dB of the predicted values, but at the higher frequencies  $\sigma_L$  is somewhat larger than predicted. There are several possible explanations. One is the small sample size, another that many of these measurements were at the limit of the equipment, and a third that terrain irregularity is so great in comparison to wave length that small errors in estimating the terrain parameter would be magnified. The Colorado R3 data show less than the calculated variability. In this case the receiver is at the top of a mesa so that many of the paths are within line of sight.

To determine whether antenna heights have a uniform effect on location variability, the differences between measured values of  $\sigma_L$  and those calculated using equation (5) are plotted in figure 6 against the sum of the

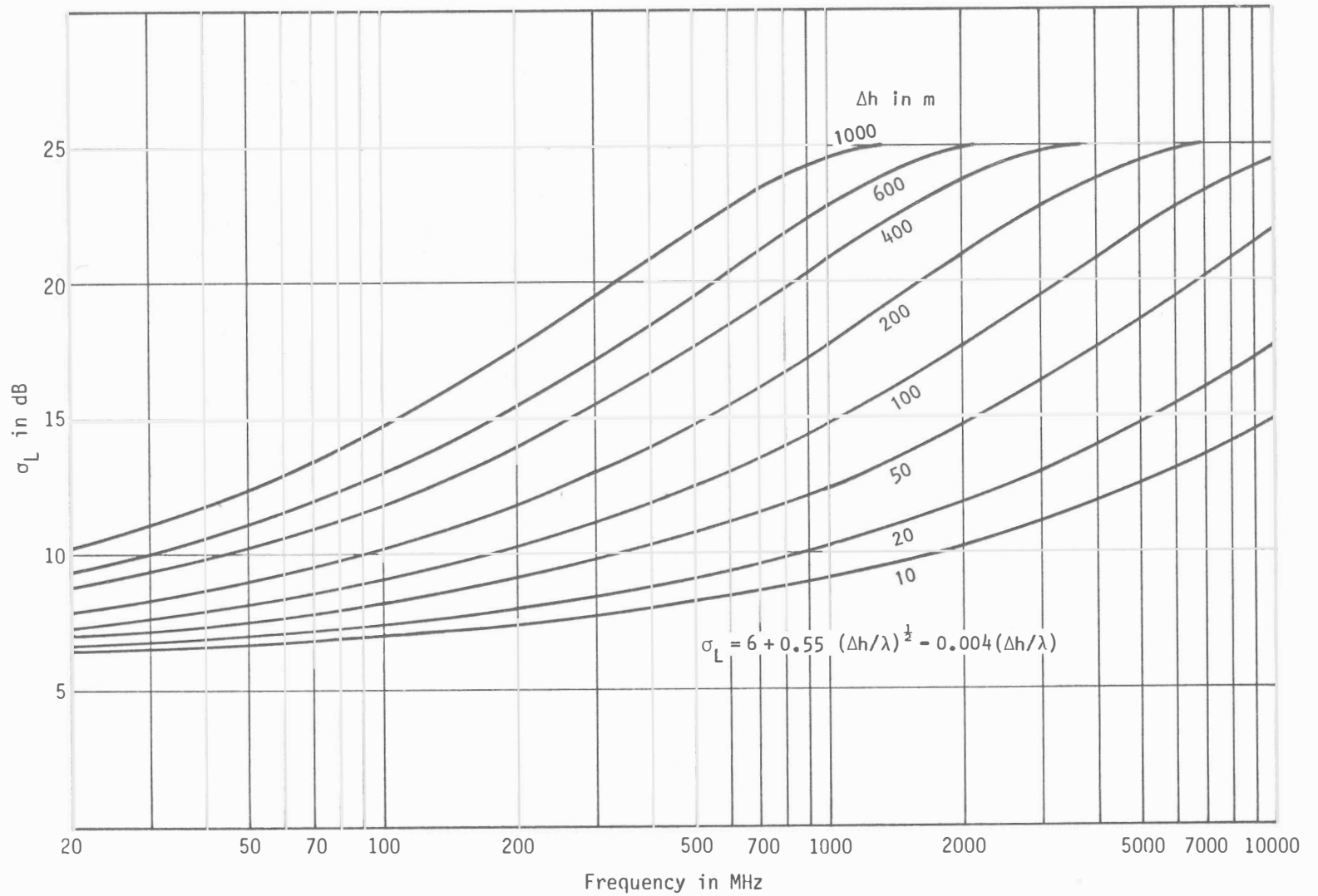


Figure 5. Curves of  $\sigma_L$  versus frequency, for several values of the terrain parameter  $\Delta h$ .

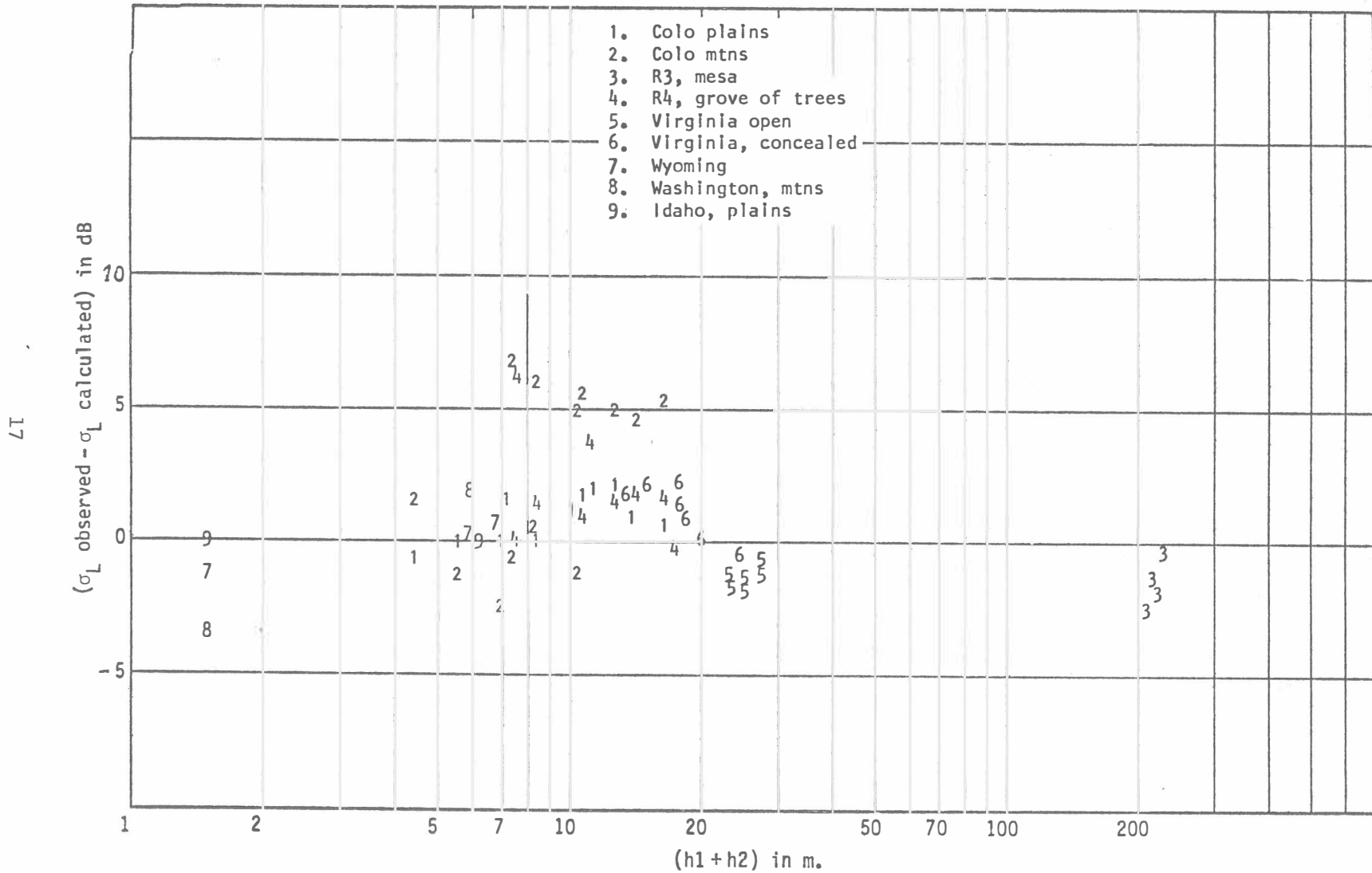


Figure 6. The difference between calculated and measured values of  $\sigma_L$  vs the sum of antenna heights in m.

antenna heights in meters. When the antennas are very low,  $(h_1 + h_2) = 1.5$  m, the predicted  $\sigma_L$  is slightly greater than that measured. As the sum of the antenna heights increases to about 15 m the observed values increase until they are somewhat greater than the calculated ones. Excluding the Colorado mountain data this relationship may be expressed as follows:

$$\text{For } (h_1 + h_2) \text{ between 1 and 15 m}$$

$$(\sigma_L \text{ observed} - \sigma_L \text{ calculated}) = -1.0 + 2 \log (h_1 + h_2). \quad (6)$$

For the R3 Colorado data, where the mesa increases the effective height so that  $(h_1 + h_2) \approx 210$  m, the observed variability is some 2.0 dB less than predicted.

As a further check on these conclusions values predicted using the relationship in (5) were compared with a large body of measurements recently analyzed by Longley and Hufford (1975). The measurements were made with very low antennas at frequencies of 172 and 410 MHz over about 130 paths in three quite different types of terrain. These included a flat, heavily forested area in Florida; a hilly, forested area in northern California; and an area in the rugged, arid mountains of Arizona. The path-to-path variability observed in all groups of data agreed well with predicted values. Differences between measured and calculated values of  $\sigma_L$  ranged from -0.5 dB to 1.5 dB, for values of  $\Delta h/\lambda$  from 23 to 274. The larger values of  $\sigma_L$ , 1.5 dB more than predicted, were observed in the Arizona mountains where there were large differences in the terrain irregularity among the radio paths. In this area values of  $\Delta h$  ranged from about 50 to more than 900 m, with a median  $\Delta h \approx 180$  m.

#### 4. SUMMARY

The work of many investigators has shown that, in a land mobile or broadcast system, the signal level varies greatly from one path to another for paths of the same length. Such path-to-path variability increases with radio frequency and with terrain irregularity, and is strongly influenced by the presence of buildings and trees near the path terminals.

In urban areas the path-to-path variability depends on the heights, density, and uniformity in size of the buildings. In a highly built-up area, such as Manhattan, the received signal may vary greatly from place to place even at frequencies of 50 to 100 MHz. At higher frequencies the phenomena

of channeling along radial streets and improved reception at street intersections are common, so the signal level may change markedly in a very short distance. In suburban areas, with two- and three-storied buildings, the presence and density of trees may have an effect equal to that of the buildings themselves.

In most urban and suburban areas, with rather smooth terrain, it appears reasonable to predict that the standard deviation,  $\sigma_L$ , of path-to-path differences in signal level is about 7 dB at VHF, increasing gradually to 9.5 or 10 dB at 3 GHz. However, much larger values must be assumed for highly built-up urban areas such as Manhattan. Also, greater variability is to be expected when the terrain is quite irregular as, for example, in San Francisco.

The present study of a large amount of data, which was obtained with low antennas in non-urban areas, has led to an expression (5) which defines the standard deviation of location variability in terms of radio frequency and terrain irregularity. Except for data obtained at UHF/SHF in a rugged mountainous area, 90% of all measurements fall within 2 dB of the predicted values. The mountain data show somewhat more variability than predicted, while measurements with very low antennas over level farmlands and signals received at the top of a high mesa show somewhat less than the predicted variability. For the latter set of data the effective receiver height is more than 200 m, and many of the path terminals are within radio line of sight.

Although for most of the measurements in this study the path terminals were placed at open sites, some of them were in cluttered surroundings. At the "open sites" in Virginia the antenna sites were selected with clear foreground areas, while at "concealed sites" they were placed in thickets of trees. Figure 3 shows greater variability at the concealed sites at all frequencies, with differences of 6 to 7 dB between concealed and open sites at the higher frequencies. Similarly at R4, which was located in a grove of trees, the data show greater variability than the R1 data even though the R4 terrain is somewhat smoother. These differences of 2 or 3 dB in  $\sigma_L$  are probably caused by the deciduous trees in the immediate foreground at R4.

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