ANNEX 2

STUDIES OF TERRAIN PROFILES

2-1 Introduction

Radio transmission loss over irregular terrain, for the frequencies and distances considered in this report, depends mainly on the profile characteristics of a great circle path between transmitting and receiving antennas. Some allowance is made for vegetation and man-made clutter, while large buildings and dense vegetation are treated in the same way as features of the terrain itself.

For point-to-point transmission loss calculations for a given terrain profile and antenna locations, the parameters of interest, in order of their usual importance, are the sum of horizon ray elevation angles θ_e, the effective antenna heights $h_{e1,2}$, the path distance d, the interdecile range of terrain elevations $\Delta h(d)$, the horizon distances $d_{L1,2}$, and the effective dielectric constant ϵ, and conductivity σ, for a terrain or sea surface. The definition, use, and importance of these parameters are explained in the body of the report.

To obtain calculated reference values of propagation attenuation for specified sets of terrain profiles and antenna locations, or to obtain estimates of variability from location to location with several or all of the above parameters fixed, within limits, and to estimate prediction errors, statistical descriptions of these parameters are needed, especially estimates of median values for commonly occurring situations. Terrain statistics were developed for selected areas by reading a large number of terrain profiles. Each profile is represented by discrete elevations at uniform distances of half a kilometer. The areas selected for terrain study include one in the tree-covered rolling hills of northeastern Ohio, and one in the plains and foothills of Colorado, where an exhaustive transmission loss measurement program was carried out (Miles and Barsis, 1966). About 100 paths, each 60 km in length, were selected at random throughout the continental United States to provide an estimate of "average" terrain statistics. Two limited regions, one entirely in the mountains crossing the Continental Divide and the other entirely in the plains, were chosen for an intensive study of correlation along and between profiles.

Within each region selected for intensive study, 36 profiles, 60 km in length, were read in each of six directions separated in azimuth by 30°, providing a total of 216 profiles that form a rather closely spaced "grid" over a 100 km square area. The 101 "random" paths throughout the continental United States were so chosen that they would not approach or cross each other. The separation between adjacent paths ranges from 60 to 320 km with a median separation of about 200 km. These "random" paths lie chiefly in four directions, N-S, E-W, NE-SW, and NW-SE. None are located in Colorado which is well represented by the "plains" and "mountains" grids and the area over which radio propagation measurements were made.

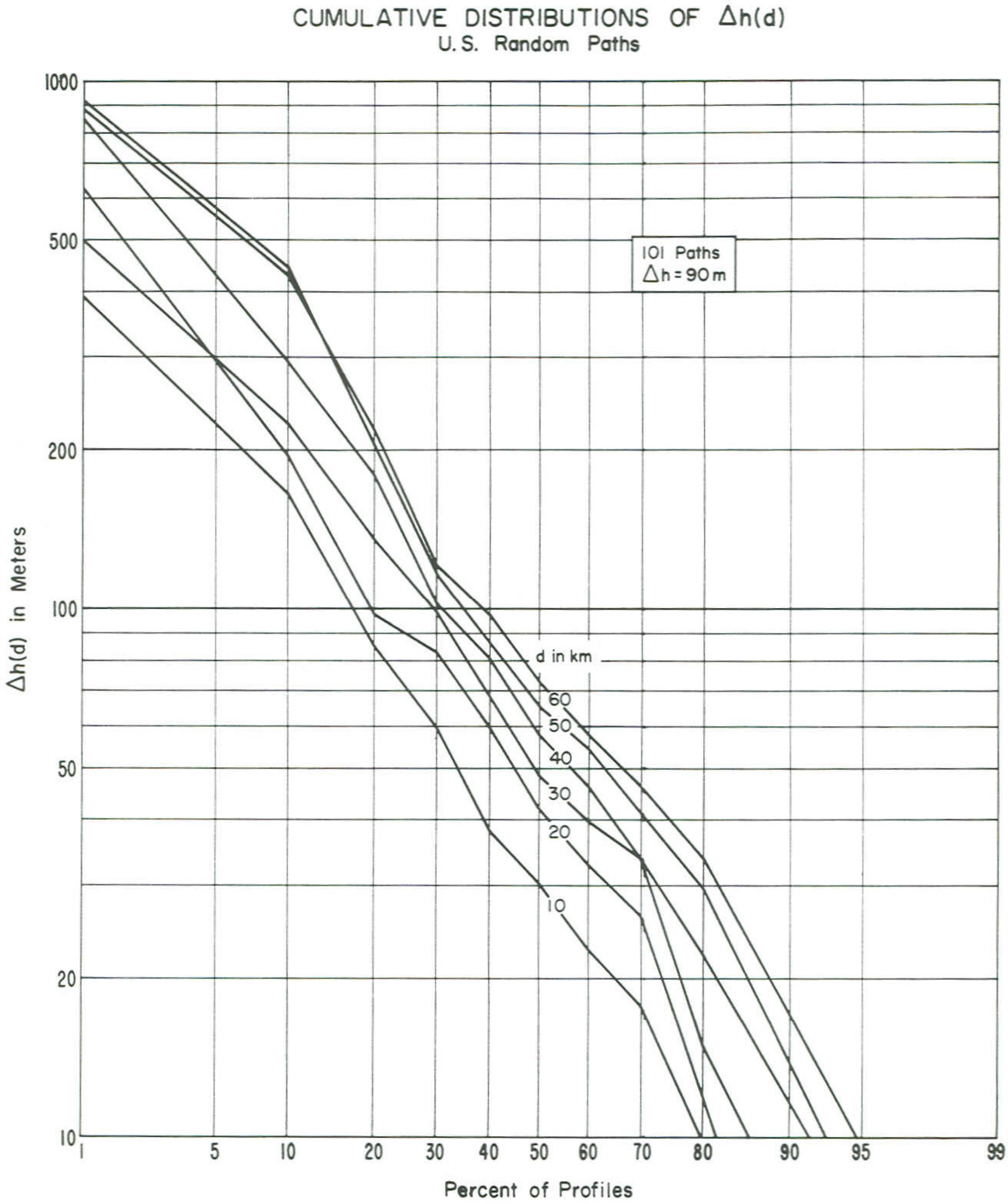
In the measurement program antenna sites were located randomly on or near roads without regard to the proximity of natural or man-made obstacles. To correspond with these measurements the path profiles were also selected arbitrarily, without regard to the location of hills or other obstacles. Each of the 60 km profiles in the mountains, plains, and random U. S. samples was considered in lengths of 5, 10, 20, 30, 40, 50, and 60 km, starting from one end of each profile, to study the effect of path length on various terrain parameters. A further statistical terrain study, assuming antenna sites placed advantageously on hilltops, should be carried out to show the improvement in radio transmission to be expected by increasing the effective height of one or both antennas.

2-2 The Terrain Parameter Δh

The path profiles described above were used to obtain estimates of several terrain parameters for paths of a given length. Of these the interdecile range $\Delta h(d)$ of terrain heights, above and below a straight line fitted by least squares to elevations above sea level, was calculated at fixed distances. Usually the median values of $\Delta h(d)$, for a specified group of profiles, increase with path length to an asymptotic value, Δh. As explained in detail in the body of the report, this parameter Δh is used to characterize nondeterministic aspects of terrain irregularity.

Figures 2.1 and 2.2 show cumulative distributions of $\Delta h(d)$ for the random U.S. mountain, and plains paths. Each distribution represents 101 profiles for random terrain and 216 profiles each for mountain and plains terrain. These distributions show a consistent increase in the median value of $\Delta h(d)$ with increasing path length. As one would expect, the variance of $\Delta h(d)$ for the randomly chosen paths is much greater than that for the more homogeneous terrain included in the plains and mountain areas.

Distributions of $\Delta h(d)$ for the area in Colorado where radio measurements were made are shown in figure 2.3. These paths are located in an area that includes plains, foothills, and mountains, but were considered in only two groups. For these much smaller groups of profiles, the same trends are observed, the median value of $\Delta h(d)$ increasing consistently with increasing path length. This trend was not observed in the


CUMULATIVE DISTRIBUTIONS OF Δh(d)
U.S. Random Paths
101 Paths
Δh = 90 m
d in km
60
50
40
30
20
10
Δh(d) in Meters
1000
500
200
100
50
20
10
1
5
10
20
30
40
50
60
70
80
90
95
99
Percent of Profiles
Figure 2.1

CUMULATIVE DISTRIBUTIONS OF Δh(d)

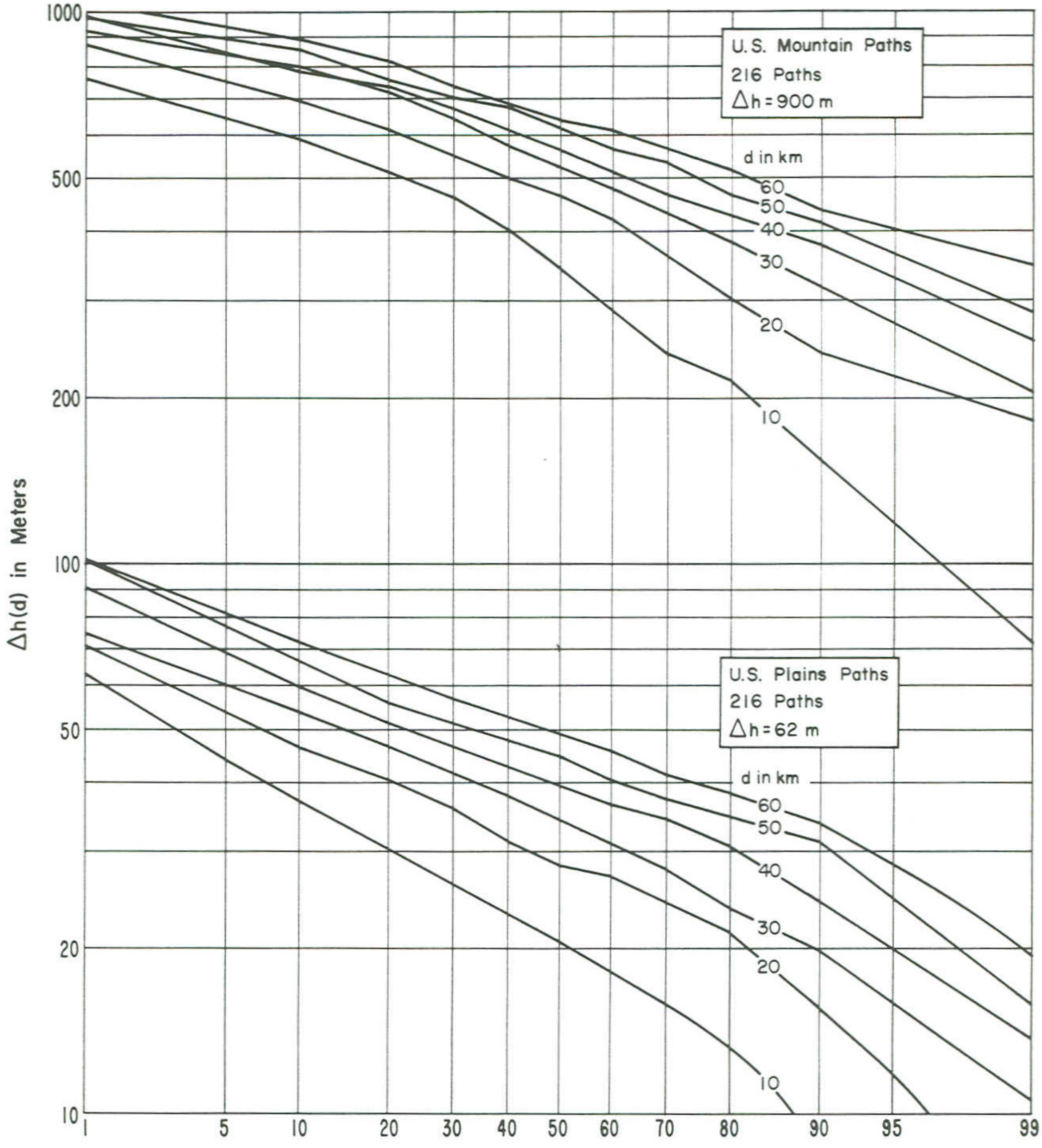


Figure 2.2

CUMULATIVE DISTRIBUTIONS OF Δh(d)

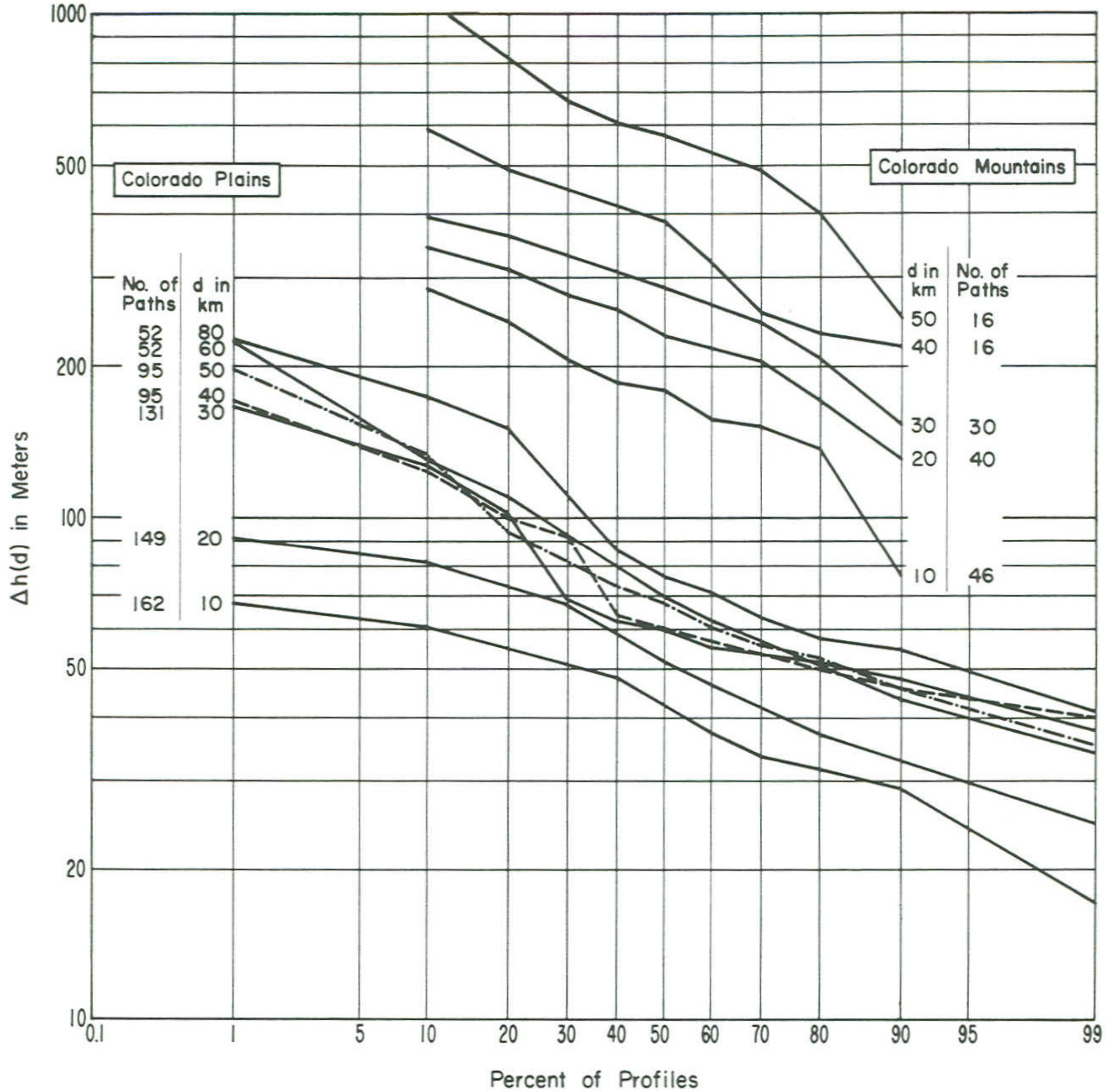


Figure 2.3

CUMULATIVE DISTRIBUTIONS OF Δh(d)

Northeastern Ohio

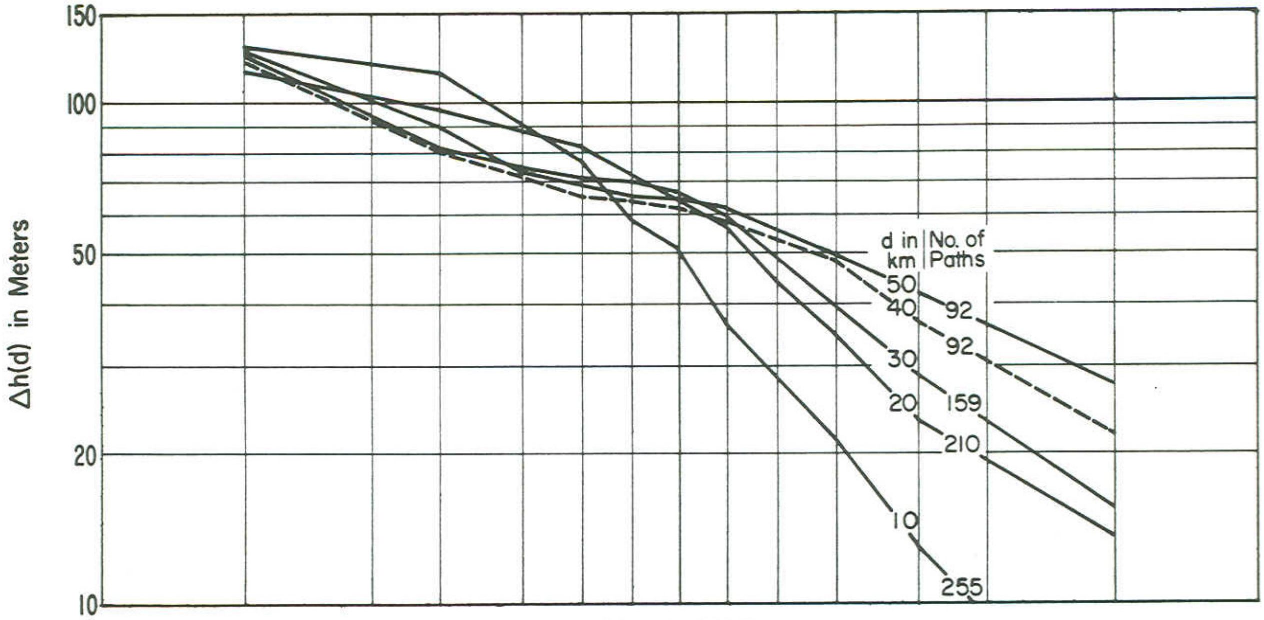


Figure 2.4 a

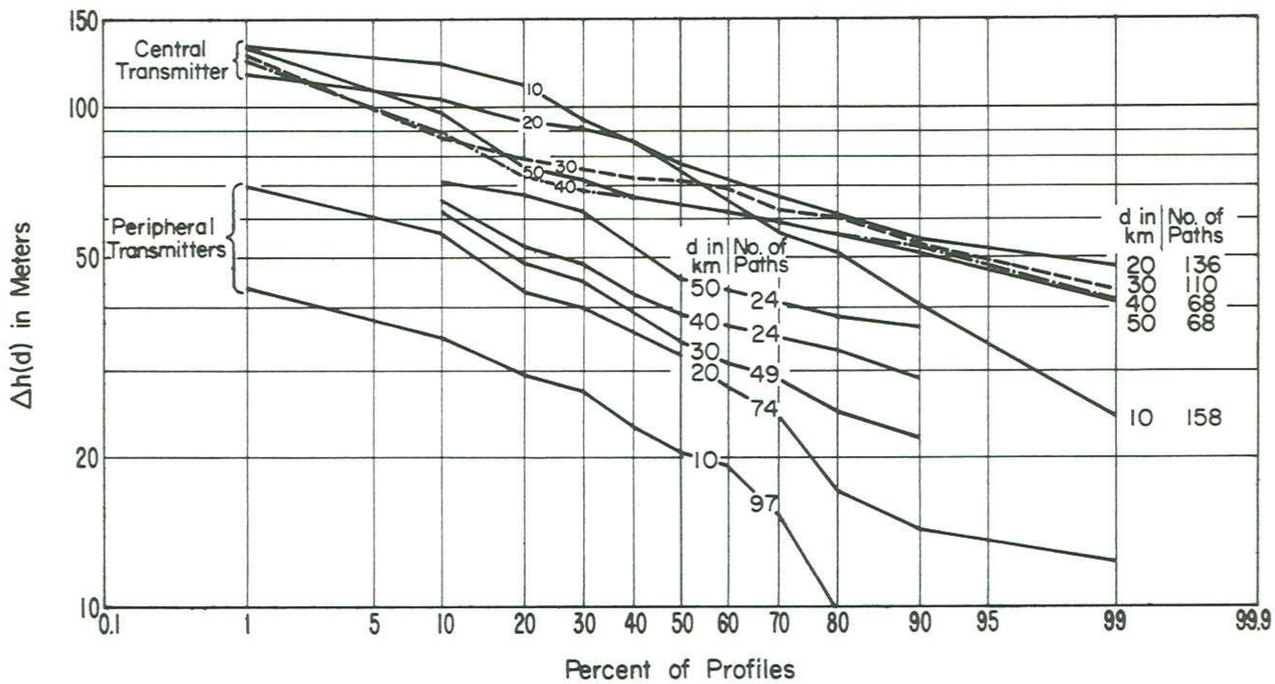


Figure 2.4 b

distribution of $\Delta h(d)$ for northeastern Ohio, as shown in figure 2.4a, where for path lengths from 20 to 50 km no consistent increase in $\Delta h(d)$ is shown. These data include a group of profiles that form radials from the location of the "central transmitter", and a smaller group of profiles that radiate from each of 5 peripheral transmitter locations. When the profiles from each of the peripheral transmitter locations are grouped together, the usual trend is observed, with the median $\Delta h(d)$ increasing consistently with path length, as shown in figure 2.4b. For the groups of paths from the location of the central transmitter the median $\Delta h(d)$ is higher at all distances but particularly for the 10- and 20-km profiles. This indicates that the terrain is more rugged in the vicinity of the central transmitter than in the remainder of the area.

Median values of $\Delta h(d)$ are plotted versus distance in figures 2.5, 2.6, and 2.7 for random, plains, and mountain paths. For each median $\Delta h(d)$, an estimate of the asymptotic value Δh was calculated using (3) of the main body of this report:

$$\Delta h(d) = \Delta h \left[1 - 0.8 \exp(-0.02\, d)\right] \text{ m}, \qquad (3)$$

where $\Delta h(d)$ and Δh are in meters and the distance d is in kilometers. Choosing appropriate values of Δh from these calculations, the smooth curves on the figures were plotted. Figure 2.5 shows for the 101 randomly chosen paths how the medians of data at each distance compare with a curve computed assuming the asymptotic value, $\Delta h = 90$ m. In the plains and mountain areas 36 profiles, 60 km in length, were read in each of 6 directions. To determine whether the terrain changes in a predictable way from one direction to another the paths in each direction were considered separately. In figures 2.6 and 2.7 each symbol

THE PARAMETER Δh(d) VERSUS DISTANCE

U. S. Random Paths

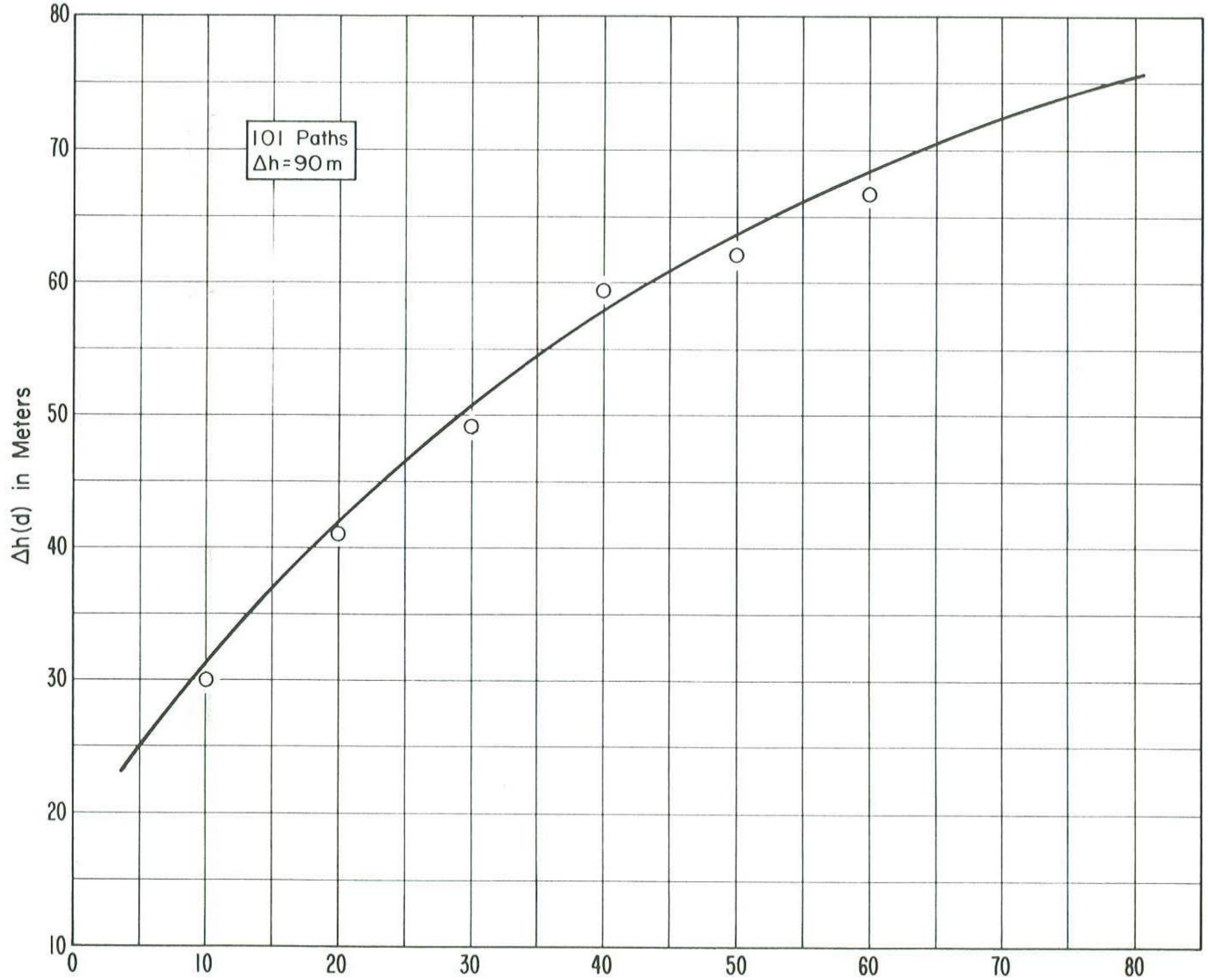


Figure 2.5

THE PARAMETER Δh(d) VERSUS DISTANCE

U.S. Plains Paths

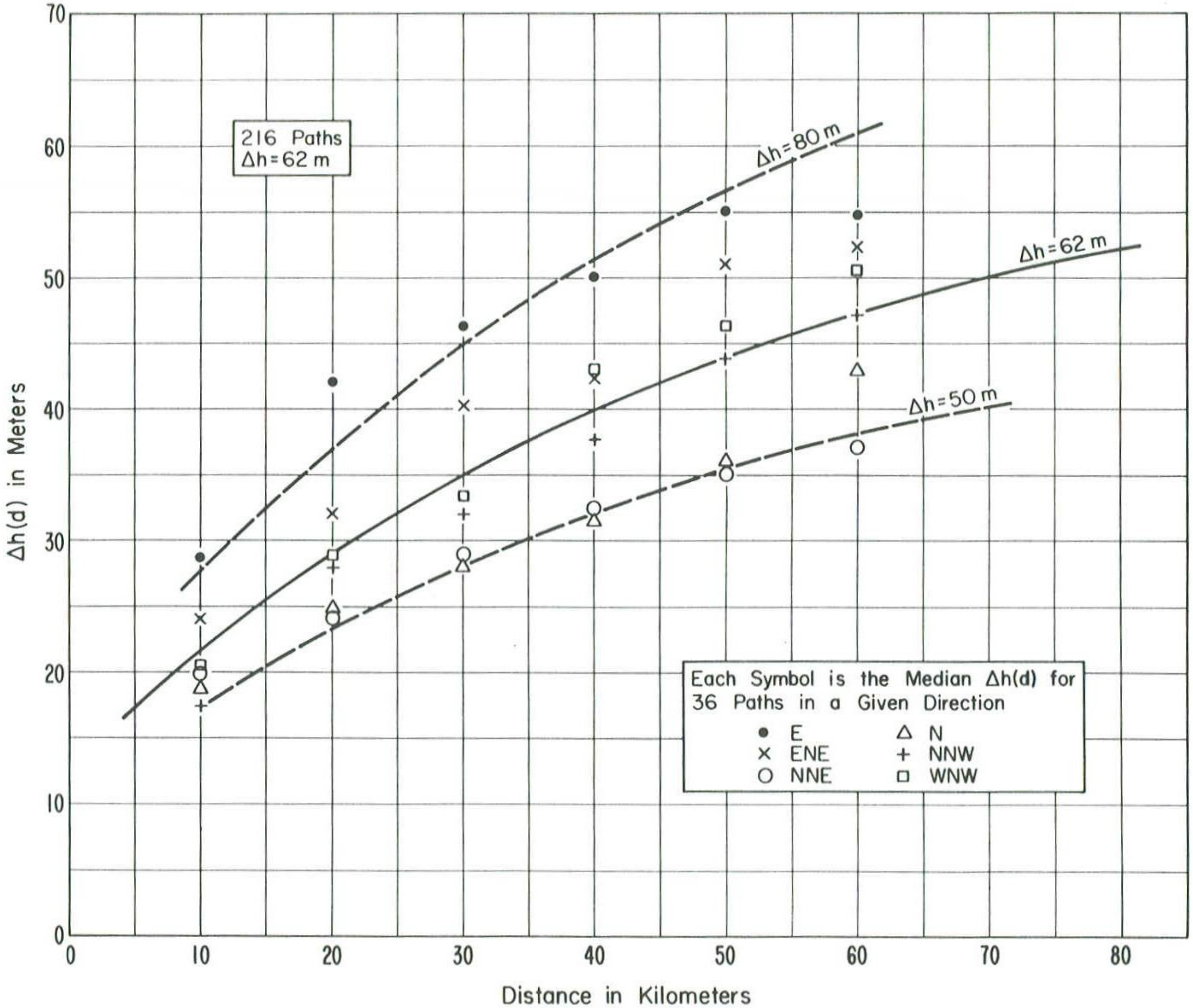


Figure 2.6

THE PARAMETER Δh(d) VERSUS DISTANCE

U.S. Mountain Paths

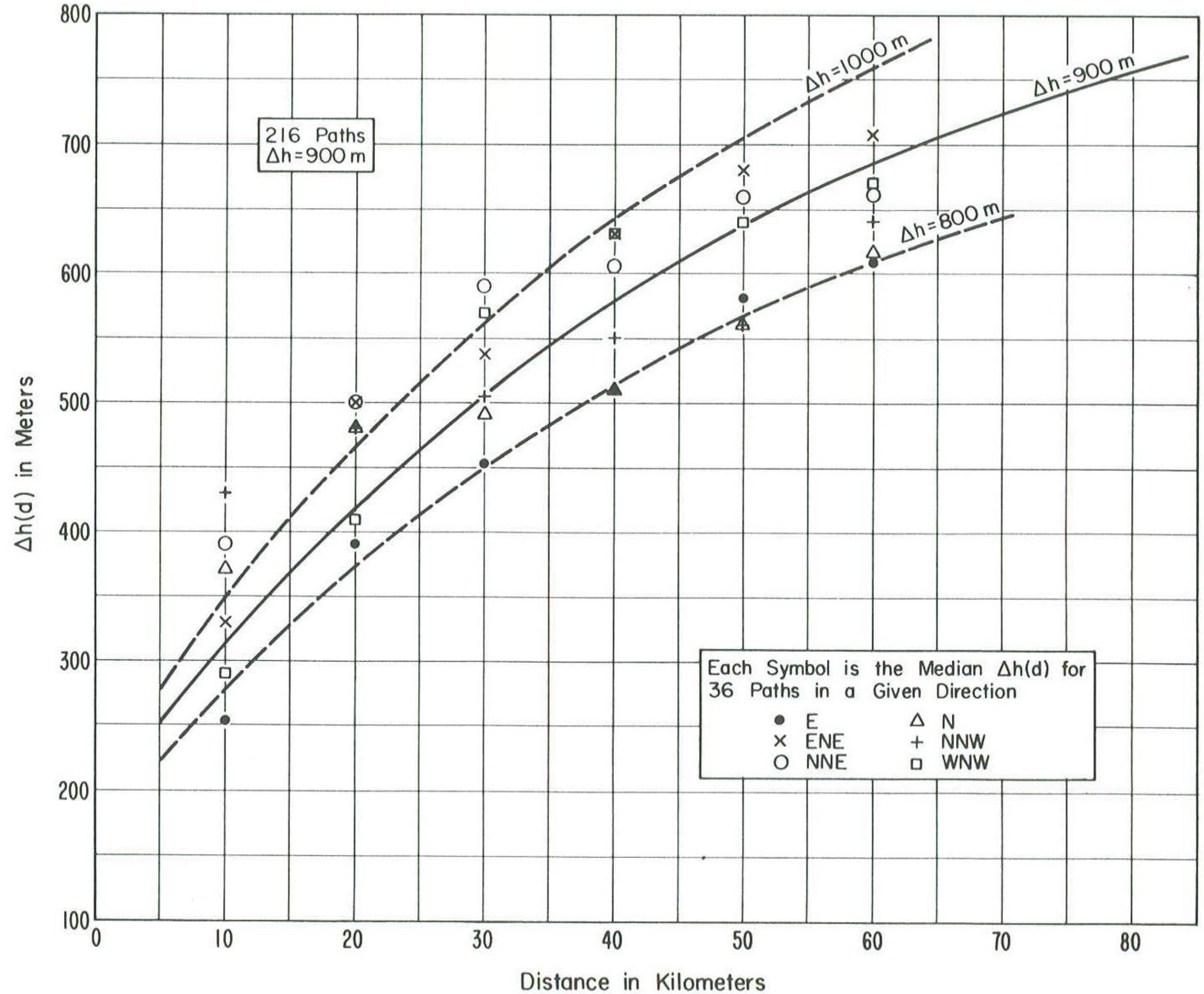


Figure 2.7